NAVIGATION STUDY FOR

JACKSONVILLE HARBOR, FLORIDA

DRAFT INTEGRATED GENERAL REEVALUATION REPORT II

AND

SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT

APPENDIX A

ATTACHMENT D

Pretreatment Appendix

SECTIONS FOR PRETREATMENT APPENDIX

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January 9, 2012

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1. PROJECT BACKGROUND

Background

This scope of work is to provide pre-treatment professional services assistance for deepening Jacksonville Harbor, Duval County, Florida. The channel is being assessed for channel deepening and widening projects. The objective of this scope of work is to provide expert assistance to the U.S. Army Corps of Engineers (USACE) regarding pre-treatment for deepening Segment 1 to approximately River Mile 13 of the Jacksonville Harbor.

Various new features as well as deepening of existing project features are proposed for Jacksonville Harbor located in Northeast Florida in the St. Johns River. Project features may be excavated to a minimum elevation of -50 feet MLLW (Mean Lower Low Water) from the current –40 feet and pre-treatment will address variable rock areas in the proposed channel improvements (deepening), turning basin(s), and wideners.

Geotechnical investigation and analyses are available from the entrance channel through river mile 20 to characterize the materials present in the estimated dredge prism. The main channel is approximately 500 feet wide over most of the straight sections.

The environmental effects on marine species is also a major consideration as well as the effects of blast overpressure at other underwater blasting projects (Appendix 1).

General Area Description

Existing core borings have been collected in the St. Johns River; however, additional investigations need to be conducted for the General Reevaluation Report (GRR). The USACE recently conducted a marine resistivity survey over the section of harbor to be deepened to identify areas of rock within the channel accompanied by borings to calibrate the resistivity data. This marine resistivity survey for this section identified maximum water depth for boring locations in the study area along the St. John's River in Jacksonville Harbor is 45 feet. Recent borings extended to below -60 feet MLLW.

Project Location

The project is located in Duval County in northeast Florida along the St. Johns River Federal Channel from near the mouth of the river upstream to the end of Segment One, Mile Marker 13, near the interim cruise terminal in Jacksonville as displayed on Figure 1.1. The first four miles where the channel enters from the Atlantic Ocean is considered to be sediment and little, if any, rock will be needed to be removed to get to the new elevation.

Figure 1.1. Jacksonville Harbor Deepening Project

2. PRE-TREATMENT METHODS TO CONSIDER WITHOUT BLASTING

The possible methods that could be considered for pre-treatment for the rock removal from the channel are either pretreatment methods using a type of mechanical excavation from a barge or by drilling and blasting from a barge or possibly both.

DESCRIPTIONS OF TECHNOLOGIES

Dredging involves mechanically penetrating, grabbing, raking, cutting, or hydraulically scouring the bottom of the waterway to dislodge the rock or sediment. Once dislodged, the sediment is lifted out of the waterway either mechanically, as with buckets, or hydraulically, through a pipe. Dredges can be categorized as either mechanical or hydraulic depending on the basic means of moving the dredged material. A subset of the hydraulic dredges employs pneumatic systems to pump the sediments out of the waterway are called pneumatic dredges.

The most fundamental difference between mechanical and hydraulic dredging equipment is the manner in which the sediments are removed. Mechanical dredges offer the advantage of removing the sediments at nearly the same solids content as the *in situ* material. That is, little additional water is entrained with the sediments as they are removed, such that the volume of the sediments is essentially the same before and after dredging.This type of removal can be accomplished with a Clamshell dredge or a dipper dredge. In contrast, hydraulic dredges remove and transport sediment in slurry form. The total volume of material is greatly increased, because the solids content of the slurry is less than that of the *in situ* materials.

The two general types of dredges most commonly used to perform navigation maintenance and construction related dredging are mechanical and hydraulic.
Both dredges are available in a wide variety of sizes.

Mechanical Dredges

Mechanical dredges remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material. The dredged material is then lifted mechanically to the surface at near-*in situ* densities. Production rates for mechanical dredges are typically lower than those for comparably sized hydraulic dredges.

Major types of mechanical dredges include the following:

- Clamshell bucket
- Backhoe
- Bucket ladder
- Dipper
- Dragline

Clamshell Bucket Dredges

The clamshell bucket dredge, also known as the grab dredge, is the most commonly used mechanical dredge in the United States.. This dredge may consist simply of a crane mounted on a spud barge, although most bucket dredges have a crane/barge system specifically designed and constructed for dredging. Buckets are classified by their capacities, which range from <1 to 50 $yd^{3.}$ The typical size range is 2-10 yd^3. Clamshell bucket dredges are available throughout North America. A bucket dredge is operated similarly to a land-based crane and bucket. The crane operator drops the bucket through the water column, allowing it to sink into the sediment on contact. The loaded bucket is then lifted, causing the jaws to close, and raised through the water column. Once above the water surface, the operator swings the bucket over the receiving container (usually a barge) and lowers the bucket to release its load. The bucket dredge usually leaves an irregular, cratered sediment surface.

A variation of the conventional dredge bucket, the enclosed dredge bucket, has been developed to limit spillage and leakage from the bucket.. The operation and deployment of the enclosed dredge bucket is identical to that of the conventional clamshell bucket discussed above.

Backhoe Dredges

Backhoes, although normally thought of as excavating rather than dredging equipment, can be used for removing contaminated sediments under certain circumstances. Backhoes are normally land based, but may be operated from a barge, and have been used infrequently for navigation dredging in deep-draft (20-ft [6-m]) channels.

Specialized backhoes include closed-bucket versions and a pontoon-mounted model especially adapted to dredging applications (see WaterMaster described in St. Lawrence Centre 1993). The latter may be equipped with a suction pump as well.

Dipper Dredge

A dipper dredge can be considered a type of backhoe dredge and has a long dipper stick that can be used in digging rock or sediment for channel depths of 50 feet or more. This type of dredge has been used on channel deepening projects in the USA.

Hydraulic Dredges

Hydraulic dredges remove and transport sediments in the form of a slurry. They are routinely used throughout the United States to move millions of cubic meters of sediment each year. The hydraulic dredges used most commonly in the United States include the conventional cutterhead, dustpan, and bucket-wheel. Certain hydraulic dredges, such as the modified dustpan, clean-up, and matchbox dredges, have been specifically developed to reduce resuspension at the point of dredging.

Hydraulic dredges provide an economical means of removing large quantities of contaminated sediments. The capacity of the dredge is generally defined by the diameter of the dredge pump discharge. The larger pumps are 24 to 36 inches in diameter. The dredged material is usually pumped to a storage or disposal area through a pipeline. The solids content is typically 10-20 percent by weight. The slurry uniformity is controlled by the cutterhead (if one is employed) and suction intake design and operation.

Cutter Suction Dredges

The cutterhead should be designed to grind and direct the sediment to the suction intake with minimal hydraulic losses. The dredge pump and cutterhead should work in tandem so that the entire volume of rock and/or sediment comes into the system, while maintaining a slurry concentration that the dredge pump is capable of handling. The pump must impart enough energy to the slurry so that the velocities in the pipeline prevent the solids from settling out in the line prior to reaching the next transport mode or remediation process. A properly designed and operated dredgehead, suction intake and pipe, pump, and discharge pipeline system can minimize sediment resuspension. Fundamentally, there are four key components of a hydraulic dredge:

Dredgeheads

Various types of dredgeheads are used to help the initial loosening and gathering of bottom sediment. Most hydraulic dredges are usually identified by the type of dredgehead used. Various types of dredgeheads are discussed below.

Cutterhead Dredges

Conventional cutterhead dredges are the most common hydraulic dredges in the United States. There are about 300 such dredges operating in the United States today. Cutterhead dredges are usually operated by swinging the dredgehead in a zig-zag pattern of arcs across the bottom. There are innovative dredgehead designs that have been developed for removing rock materials.

Suction Dredges

This category includes those hydraulic dredges that do not employ a cutterhead. Such dredges may use water jets to help loosen sediments.

Hydraulic Cutterhead Dredges

These dredges use a combination of mechanical action and hydraulic pumping, but would include cutterheads to remove the rock that is broken into small particles.

Hybrid Dredges

These dredges use a combination of mechanical action and hydraulic pumping, include the bucket wheel, screw impeller, and disc-bottom dredgeheads.

3. GEOLOGY OF JACKSONVILLE HARBOR

Geologic Review

To evaluate the geology in the bottom of the channel rock cores, borings, and resistivity study were used. Some rock cores were evaluated for compressive strength, RQD and % recovery.

The geology consists of silica and other sands, silt to silty clay, weathered limestone. moderately weathered limestone and some strong limestone.

Figure 3.1, entitled Jacksonville Project Features shows areas of anticipated rock where pre-treatment may be necessary.

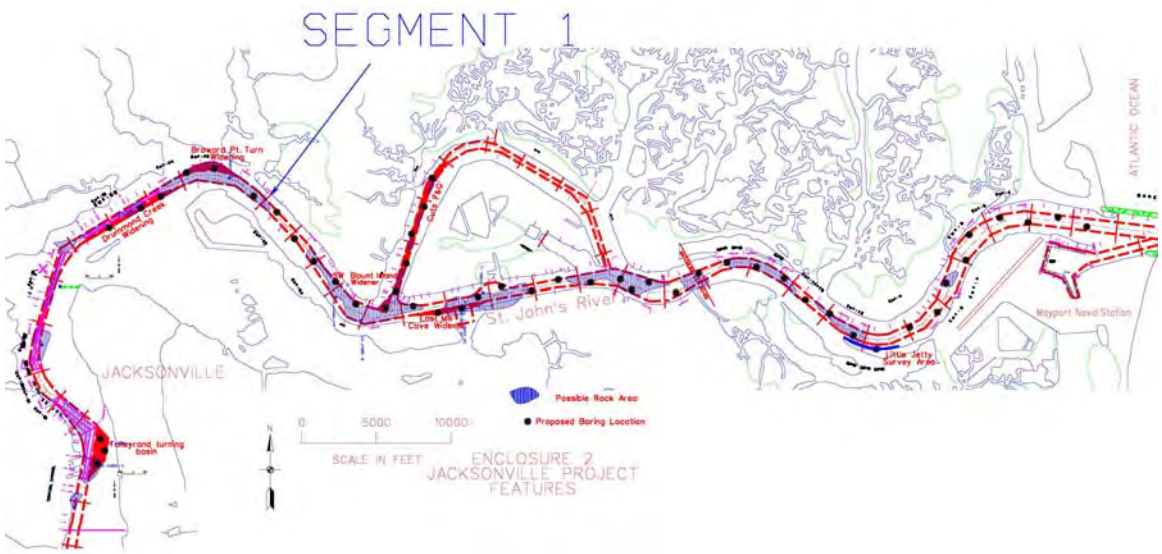


Figure 3.1 Jacksonville Project Features

Compilation and evaluation of the Resistivity Data would indicate that much of the materials in the channel are silts, sand and weak weathered limestone rock. At 61, 500 feet to 88,000 and at 43,000 to 62,000 feet there are zones of harder limestone. At 43,500 to 45,000 (cut46) apparently has limestone within the potential maximum dredge prism and again 52000 to 55000 (Cut44). Based on resistivity weaker LS exists from 59000 through 62000, but still needs to be verified. The quality of the limestone needs to be fully evaluated.

The hardest limestone seems to be at 71,500 to 83,000 and 52,000 to 56,000 feet. The areas of the channel would probably need to be blasted for pretreatment. Cut 44 would seem to require the most blasting.

Geology Near Residential Areas

All residential areas in close proximity to either side of the channel were visited to determine the distance from the houses to the waters edge and the type of home construction. Residential areas abut cuts 39 through 42 as well as cuts 8 through 13. The quality of the rock in the channel has not been fully evaluated and blasting may be necessary in the cuts listed above.

Most highly weathered bedded limestones should be able to be dug with a cutter suction barge or a dipper barge. If explosives would need to be used then small charges to “bump” the rock and loosen the bedding should be sufficient. The blast vibrations may be felt by the residence but would be of such low level that property damage could not occur. Air overpressure would be minimal because any explosives would be fired under 40 feet of water.

The topics of vibration and air overpressure will be discussed later in this report.

ESTIMATED SECTIONS NEEDING PRETREATMENT

The channel is about 500 feet wide, depth will be increased from about –40 to –50 ft or about 10 feet of rock will have to be removed in the worst case The blasting will only need to be done in areas where the rock is too hard to be removed with a cutter suction dredge. The locations for pretreatment will need to be accessed following the proper explosive transportation requirements (Appendix 2).

Anticipated Blasting Locations

The geologic data I have reviewed would indicate that the cut requiring blasting would be Cut 44 that would seem to have the most volume of limestone. There are other smaller areas of limestone along the channel that may need blasting if the forces from a dipper barge or cutter suction barge are not capable of removing the more massive, stronger limestone. Similar resistivity response is seen along the channel in other cuts that need to be tested to determine the need for blasting. Based on boring data to date and the resistivity there may be other cuts that would require blasting too.

The depth of rock that needs to be removed to attain an elevation of –50 varies along the channel. In most cases the rock depth that has to be removed is about 3 to 5 feet to get to –50 ft depth and not 10 as one might expect. This means that blastholes could be shorter requiring less explosives and explosives decking than if 10 feet of rock had to be removed. Blasting methods will be discussed later in the report.

Additional Data Needed

It will be unknown until the cutter suction barge or the dipper barge works through the channel exactly where high spots occur and need to blasted. The geologic data showing limestone in Cut 44 and some other smaller limestone areas would be most likely areas blasted as the means of preconditioning.

DREDGE SELECTION FOR JACKSONVILLE

The rock in the bottom of the channel varies in hardness. The material ranges from sediment to hard limestone. If dredges are to be used as the partial or total excavation method for the rock areas then a dredge must have the capability to break, remove and excavate rock as described in the geologic section of this report.

In other dreding projects such as Kill Van Kull in New York, a dipper dredge (Figure 3.2) was used. The dredge had the capability of digging some of the previously blasted rock in the bottom but could not dig the solid rock materials.

A cutterhead suction dredge (Figure 3.3), with a cutterhead made specifically to break softer rock, would possibly be the best choice for breaking and removing softer rock. The rock areas that could not be economically broken and removed with the cutterhead suction barge would need to be blasted and removed with either the cutterhead suction barge or the dipper barge.

The geologic information borings, resistivity and coring results show that blasting in some areas of the channel will be necessary. The blasting can be minimized if the softer rock is mechanically removed and only the hard materials would need to be blasted.

Figure 3.2. Dipper Barge (Great Lakes, Kill Van Kull)

Figure 3.3. Cutter Suction Barge

4. BLASTING METHODS USED IN HARBOR DEEPENING

The only method that can be used to break massive hard rock so that it can be removed from the channel by dredging is blasting. Blasting has been used in harbor deepening projects in many locations in the USA and also in other countries. Competent contractors have used blasting in harbor deepening projects in more congested metropolitan settings for decades without causing environmental damage or property damage to industry or residents adjoining the channel. Projects such as the numerous Kill Van Kull projects in New York and New Jersey harbors, Boston, Portsmouth, NH and Miami harbor are just a few of the projects that were successfully completed on the East Coast of America in the past few decades using blasting.

BLASTING ENVIRONMENTAL EFFECTS

There are three effects of blasting that the contractor can control. The underwater blasting causes ground vibration, air overpressure and limited shock waves. The remainder of this report identifies, describes and quantifies these three environmental effects of blasting. The methods to control the blast effects are also discussed.

FUNDAMENTALS OF UNDERWATER BLAST DESIGN

Sources of Explosive's Energy

Two basic forms of energy are released when high explosives react. The first type of energy will be called shock energy. The second type will be called gas energy. Although both types of energy are released during the detonation process, the blaster can select explosives with different proportions of shock or gas energy to suit a particular application. If explosives were used in an unconfined manner, such as mud capping boulders (commonly called plaster shooting) or for shearing structural members in demolition, the selection of an explosive with high shock energy would be advantageous. On the other hand, if explosives are being used in boreholes and are confined with stemming materials, an explosive with a high gas energy output would be beneficial.

To help form a mental picture of the difference between the two types of energy, compare the difference in reaction of a low and high explosives. Low explosives are those, which deflagrate or burn very rapidly. These explosives may have reaction velocities of two to five thousand feet per second and produce no shock energy. They produce work only from gas expansion. A very typical example of a low explosive would be black powder. High explosives detonate and produce not only gas pressure, but also another energy or pressure which is called shock pressure. Figure 4.1 shows a diagram of a reacting cartridge of low explosive. If the reaction is stopped when the cartridge has been partially consumed and the pressure profile is examined, one can see a steady rise in pressure at the reaction until the maximum pressure is reached. Low explosives only produce gas pressure during the combustion process. A high explosive detonates and exhibits a totally different pressure profile (Figure 4.1).

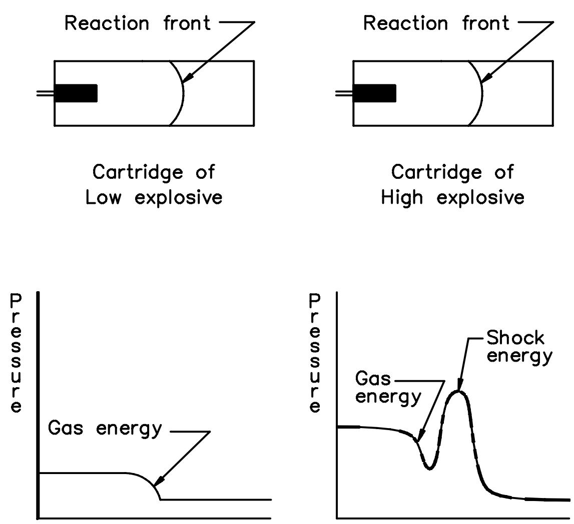


Figure 4.1 Pressure Profiles for Low and High Explosives

Shock Energy

In high explosives, a shock pressure spike at the reaction front travels through the explosive before the gas energy is released. There are, therefore, two distinct separate pressures resulting from a high explosive and only one from a low explosive. The shock pressure is a transient pressure that travels at the explosive's rate of detonation. The gas pressure follows thereafter. The shock pressure can also cause fish kill in underwater blasting (Appendix 1).

The shock energy is commonly believed to result from the detonation pressure of the explosion. The detonation pressure is a function of the explosive density times the explosion detonation velocity squared and is a form of kinetic energy. Determination of the detonation pressure is very complex. There are a number of different computer codes written to approximate this pressure. Unfortunately, the computer codes come up with widely varying answers. Until recently, no method existed to measure the detonation pressure. Now that methods exist to produce accurate measurements, one would hope that the computer codes would be corrected. Until that time occurs, one could use one of a number of approximations to achieve a number that may approximate the detonation pressure. As an example, one could use:

$$P = \frac{4.18x10^{-7}\ SG_e\ Ve^2}{1 + 0.8\ SG_e}$$

where:

P	=	Detonation pressure (Kbar, 1 Kilobar @ 14,504 psi)
SG_e	=	Specific gravity of the explosive
Ve	=	Detonation velocity (ft/s)

The detonation pressure or shock energy can be considered similar to kinetic energy and is maximum in the direction of travel, which would mean that the detonation pressure would be maximum in the explosive cartridge at the end opposite that where initiation occurred. It is generally believed that the detonation pressure on the sides of the cartridge is virtually zero, since the detonation wave does not extend to the edges of the cartridge. To get maximum detonation pressure effects from an explosive, it is necessary to place the explosives on the material to be broken and initiate it from the end opposite that in contact with the material. Laying the cartridge over on its side and firing in a manner where detonation is parallel to the surface of the material to be broken reduces the effects of the detonation pressure. Instead, the material is subjected to the pressure caused by the radial expansion of the gases after the detonation wave has passed. Detonation pressure can be effectively used in blasting when shooting with external charges or charges which are not in boreholes. This application can be seen in mud capping or plaster shooting of boulders or in the placement of external charges on structural members during demolition (Figure 4.2).

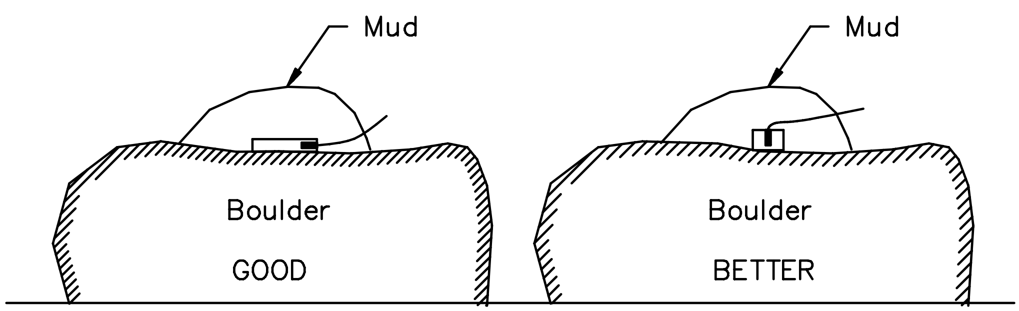


Figure 4.2. Shock Energy from Surface Charges

Gas Energy

The gas energy released during the detonation process causes the majority of rock breakage in rock blasting with charges confined in boreholes. The gas pressure, often called explosion pressure, is the pressure that is exerted on the borehole walls by the expanding gases after the chemical reaction has been completed. Explosion pressure results from the amount of gases liberated per unit weight of explosive and the amount of heat liberated during the reaction. The higher the temperature produced, the higher the gas pressure. If more gas volume is liberated at the same temperature, the pressure will also increase. For a quick approximation, it is often assumed that explosion pressure is approximately one-half of the detonation pressure (Figure 4.3).

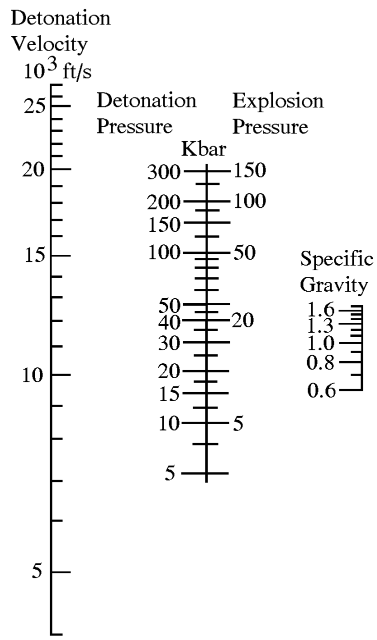


Figure 4.3 Nomograph of Detonation and Explosion Pressure

It should be pointed out that this is only an approximation and conditions can exist where the explosion pressure exceeds the detonation pressure. This explains the success of ANFO that yields a relatively low detonation pressure, but relatively high explosion pressure. Explosion pressures are calculated from computer codes or measured using underwater tests. Explosion pressures can also be measured directly in boreholes, however, few of the explosive manufacturers use the new technique in rating their explosives. A review of some very basic explosive chemistry helps one to understand how powdered metals and other substances affect explosion pressures.

CONFINED CHARGES IN BOREHOLES

Three basic mechanisms contribute to rock breakage with charges confined in boreholes. The first and least significant mechanism of breakage is caused by the shock wave. At most, the shock wave causes microfractures to form on the borehole walls and initiates microfractures at discontinuities in the burden. This transient pressure pulse quickly diminishes with distance from the borehole and since the propagation velocity of the pulse is approximately 2.5 to 5 times the maximum crack propagation velocity, the pulse quickly outruns the fracture propagation.

The two major mechanisms of rock breakage result from the sustained gas pressure in the borehole. When the solid explosive is transformed into a gas during the detonation process, the borehole acts similar to a cylindrical pressure vessel. Failures in pressure vessels, such as water pipes or hydraulic lines, offer an analogy to this mechanism of rock breakage. When the pressure vessel is overpressurized, the pressure exerted perpendicular to the confining vessel's walls will cause a fracture to occur at the weakest point in the pressure vessel. In the case of frozen water pipes, a longitudinal split occurs parallel to the axis of the pipe (Figure 4.4).

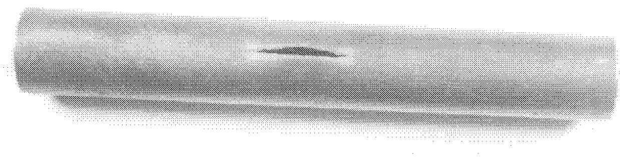


Figure 4.4 Fracture of Frozen Water Pipes

The same phenomenon occurs in other cylindrical pressure vessels due to the generation of hoop stresses. If a borehole were considered a pressure vessel, one would expect fractures to orient themselves parallel to the axis of the borehole. The major difference between pressurizing a borehole and pressurizing a water pipe is rate of loading. A borehole is over-pressurized almost instantaneously and therefore does not fail at one weakest point along the borehole wall. Instead, it will simultaneously fail in many locations. Each resulting fracture will be oriented parallel to the axis of the borehole. Failure by this mechanism has been recognized for many years and is commonly called radial cracking (Figure 4.5).

Figure 4.5 Radial Cracking in Plexiglas

Direction and extent of the radial crack system can be controlled by the selection of the proper distance from the borehole to the face (burden) (Figure 4.6).

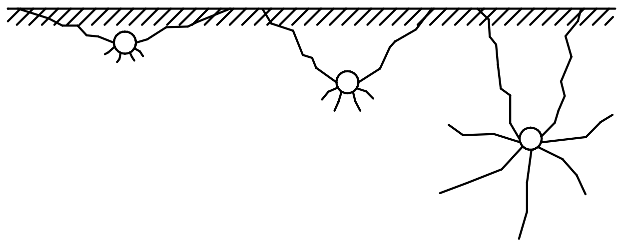


Figure 4.6 Influence of Distance to Face on Radial Crack System

The second major breakage mechanism occurs after the radial cracking has been completed. There is a time lag before the second breakage mechanism goes into play. The second mechanism influences the breakage perpendicular to the axis of the charge.

Before the second breakage mechanism is discussed, form a mental picture of what has happened during the radial cracking process. Stress wave energy (shock) has caused minor cracking or microfracturing on the borehole walls and at discontinuities throughout the burden. The sustained gas pressure, which follows the shock pressure, puts the borehole walls into tension due to the hoop stresses generated and causes the existing microfractures to grow. The high-pressure gases extend fractures throughout the burden. The burden in massive rock is transformed from a solid rock mass into one that is broken by the radial cracks in many wedge-shaped or pie-shaped pieces. These wedges function as columns, supporting the burden weight. Columns become weaker if their length to diameter ratio or slenderness ratio increases. Therefore, once the massive burden is transformed into pie-shaped pieces with a fixed bench height, it has been severely weakened due to the fact that its slenderness ratio has increased.

The work process has not yet been completed since the expanding borehole still contains very high-pressure gases. These gases subject the wedges to forces acting perpendicular to the axis of the hole. One can say they are pushing towards relief or towards the line of least resistance. This concept of relief perpendicular to the axis of the hole has been known for well over a hundred years. Relief must be available perpendicular to the axis of the hole for borehole charges to function properly. If relief is not available, only radial cracks will form and boreholes will crater or the stemming will be blown out. In either case, the fragmentation suffers and environmental problems result.

BENCH STIFFNESS

In most blasting operations, the first visible movement occurs when the face bows outward near the center. In other words, the center portion of the face is moving faster than the top or bottom of the burden (Figure 4.7).

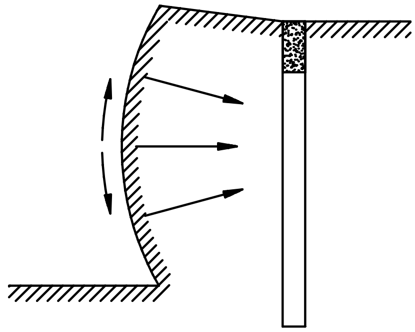


Figure 4.7 Axisymmetric Bending Diagram

This type of bowing or bending action does not always occur. One can find cases where instead of the center bowing outward, the top or bottom portion of the burden is cantilevering outward (Figure4.8).

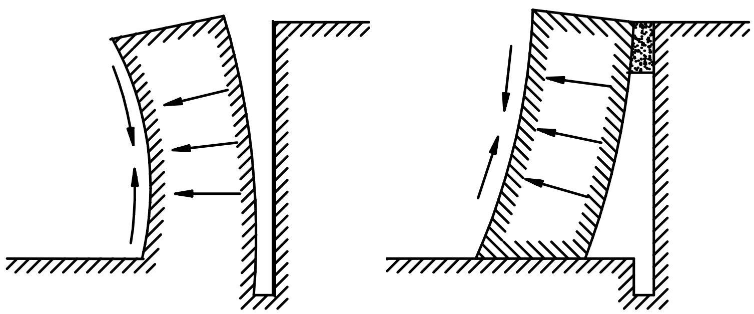


Figure 4.8 Cantilever Bending Diagram

In either of these cases, the differential movement causes the burden to break in the third dimension. This breakage mechanism has been called flexural rupture or flexural failure. To properly discuss flexural failure, one must realize that these individual pie-shaped columns of rock caused by the radial cracking will also be influenced by a force perpendicular to the length of the column. This would be similar to beam loading conditions. When one discusses beam loading, the stiffness ratio is significant. The stiffness ratio relates the thickness of the beam to its length. The effect of the stiffness can be explained by using, as an example, a full-length pencil. It is quite easy to break a pencil with the force exerted with one's fingers. However, if the same force is exerted on a two-inch long pencil, it becomes more difficult to break. The pencil's diameter has not changed, the only thing that has changed is its length. A similar stiffness phenomenon also occurs in blasting. The burden rock is more difficult to break by flexural failure when bench heights approach the burden dimension in length. When bench heights are many times the burden in length, the burden rock is more easily broken.

Two general modes of flexural failure of the burden exist. In one case, the burden bends outward or bulges in the center more quickly than it does on the top or bottom. In the second case, the top or the bottom of the burden moves at a higher rate than the center. When the burden rock bulges at its center, tensile stresses result at the face and compression results near the charge. Under this type of bending condition, the rock will break from the face back toward the hole (Figure 4.7). This mode of failure generally leads to desirable breakage.

In the second case, the rock is cantilevered outward (Figure 4.8) and the face is put into compression and the borehole walls are in tension.

This second case is undesirable. This mechanism occurs when cracks between blastholes link before the burden is broken and is normally caused by insufficient blasthole spacings. When the cracks between holes reach the surface, gases can be prematurely vented before they have accomplished all potential work. Airblast and flyrock can result along with potential bottom problems.

The bending mechanism or flexural failure is controlled by selecting the proper blasthole spacing and initiation time of adjacent holes. When blasthole timing results in charges being delayed from one another along a row of holes, the spacing must be less than that required if all the holes in a row were fired simultaneously. The selection of the proper spacing is further complicated by the stiffness ratio. As bench heights are reduced compared to the burden, one must also reduce the spacing between holes to overcome the problems of stiffness.

EFFECTS OF BLASTHOLE LENGTH

The rock breakage process occurs in four distinctive steps. As the explosive detonates, a stress wave moves through the rock uniformly in all directions around the charge. Radial cracks then propagate predominantly toward the free face. After the radial cracking process is finished, high-pressure gases penetrate into the cracks approximately 2/3 of the distance from the hole to the face throughout the radial crack system. Only after the gas has time to penetrate into the crack system are the stresses on the face of sufficient magnitude, to cause the face to move outward. Before the face begins to move and bend outward, fractures are created in the third dimension as a result of the flexural failure or bending.

CALCULATION OF THE BURDEN

Burden distance is defined as the shortest distance to relief at the time the hole detonates (Figure 4.9). Relief is normally considered to be either a ledge face or the internal face created by a row of holes that have previously shot on an earlier delay. The selection of the proper burden is one of the most important decisions made in any blast design. Of all the design dimensions in blasting, it is the most critical. If burdens are too small, rock is thrown a considerable distance from the face. Airblast levels are high and the fragmentation may be excessively fine. If burdens are too large, severe backbreak and back shattering results on the back wall. Excessive burdens may also cause blastholes to geyser throwing flyrock considerable distances, vertical cratering and high levels of airblast will occur when blastholes relieve by blowing out. Excessive burdens cause overconfinement of the blastholes, which result in significantly higher levels of ground vibration per pound of explosive used. Rock breakage can be extremely coarse and bottom or toe problems often result. Of all the design variables, there is the least allowable error in the burden dimension. Other variables are more flexible and will not produce the drastic differences in results, as would the same proportion of error in the burden dimension.

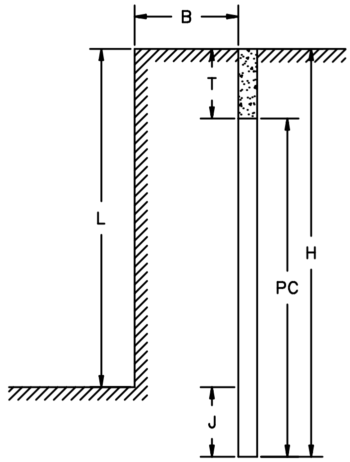


Figure 4.9 Symbols for Blast Design

where:

B	=	Burden
T	=	Stemming
J	=	Subdrilling
L	=	Bench height
H	=	Blasthole depth
PC	=	Powder column length

When an operator is moving into a new area where he has no previous experience, he would have only general rock and explosive characteristics to work with. When moving into a new area, especially one where there are residents nearby, it is essential that the first shot not be a disaster. To approximate burden under these situations, the following empirical formula proposed by Konya is helpful.

$$B = \left(\frac{2\ SG_e}{SG_r} + 1.5 \right) D_e$$

where:

B	=	Burden (ft)
SG_e	=	Specific gravity of explosive
SG_r	=	Specific gravity of rock
D_e	=	Diameter of explosive (in)

Example 4.1

An operator has designed a blasting pattern in a limestone formation using 3 inch blastholes. The 3 inch blastholes will be loaded with a semigelatin dynamite. The semigelatin has a specific gravity of 1.3. Limestone has a specific gravity of 2.6, while the diameter of cartridge in a 3 inch hole is 2-1/2 inches. The Burden Equation can be used to determine the burden (Rock density given in Table 4.1).

$$B = \left(\frac{2\ SG_e}{SG_r} + 1.5 \right) D_e = \left(\frac{2 \times 1.3}{2.6} + 1.5 \right) \times 2.5 = 6.25 \text{ ft}$$

In the general case, burdens, which are used on the job, will be reasonable if they are within plus or minus 10% of the value obtained from the above equation. Rock density is used in the Equation as an indication of matrix strength. There is a relationship between rock density and rock strength. The denser the rock, the more energy needed to overcome its tensile strength and to cause breakage to occur. There is also a relationship between the amount of energy needed to move rock. The denser the rock the more energy needed to move it. Explosive strength characteristics can be approximated using specific gravity because the stronger the explosive, the denser the explosive. If the strength of explosives were the same on a unit weight basis, then strength would be proportional to the density. However, there are differences also in explosive energy on a unit weight basis. Those differences as compared to the differences in density are normally quite small, which allow the use of the Equation as a first approximation.

TABLE 4.1 ROCK DENSITY

ROCK TYPE	SPECIFIC GRAVITY	ton/yd^3
Basalt	2.8 - 3.0	2.57
Diabase	2.6 - 3.0	2.36
Diorite	2.8 - 3.0	2.50
Dolomite	2.8 - 2.9	2.43
Gneiss	2.6 - 2.9	2.43
Granite	2.6 - 2.9	2.30
Hematite	4.5 - 5.3	4.12
Limestone	2.4 - 2.9	2.23
Marble	2.1 - 2.9	2.09
Micaschist	2.5 - 2.9	2.30
Quartzite	2.0 - 2.8	2.16
Sandstone	2.0 - 2.8	2.03
Shale	2.4 - 2.8	2.16
Slate	2.5 - 2.8	2.23
Trap Rock	2.6 - 3.0	2.36

Geologic Correction Factors

No one number will suffice as the exact burden in a particular rock type because of the variable nature of geology. Even when strength characteristics are unchanged the manner of rock deposition and geologic structure must also be considered in the blast design. The manner in which the beds are dipping, influences the design of the burden in the pattern.

There are two rock strengths that the explosive energy must overcome. There is a tensile strength of the rock matrix and the tensile strength of the rock mass. The tensile strength of the matrix is that strength which one can measure using the Brazilian or modulus or rupture test conducted on a uniaxial testing machine. Mechanical testing procedures would dictate that a massive undamaged sample of material be used for testing. A test may have biased results because one uses intact samples rather than those that are already broken. By doing so, only the matrix strength is being measured and not the strength of the rock mass. The mass strength can be very weak while the matrix strength can be strong. For example, one can have a very strong rock that is highly fractured, broken, foliated and laminated. The rock mass, however, could be on the verge of collapse simply due to the rock structure.

To estimate the deviation from the normal burden formula for unusual rock structure, two constants are incorporated into the formula. Kd is a correction for the rock deposition and Ks is a correction for the geologic structure. Kd values range from 1.0 to 1.18 and describe the dipping of the beds (Table 4.2). The classification method is broken into three general cases of deposition, beds steeply dipping into the cut, beds steeply dipping into the face or into the massive rock, and other cases of deposition.

TABLE 4.2 CORRECTIONS FOR ROCK DEPOSITION

BEDDING ORIENTATION	Kd
Bedding steeply dipping into cut	1.18
Bedding steeply dipping into face	0.95
Other cases of deposition	1.00

The correction for the geologic structure takes into account the fractured nature of the rock in place, the joint strength and frequency as well as cementation between layers of rock. The correction factors for rock structure ranges from 0.95 to 1.30 (Table 4.3). Massive intact rock would have a Ks value of 0.95 while heavily broken fractured rock could have a Ks value of about 1.3.

TABLE 4.3 CORRECTIONS FOR GEOLOGIC STRUCTURE

GEOLOGIC STRUCTURE	Ks
Heavily cracked frequent weak joints, weakly cemented layers	1.30
Thin well-cemented layers with tight joints	1.10
Massive intact rock	0.95

The revised burden equation utilizing the geology correction factors would be:

$$Bg = Kd \times Ks \times B$$

Where:

Bg = Geologically corrected burden

B = Burden calculated with the Konya burden equation
Kd = Correction for rock deposition
Ks = Correction for geologic structure

CALCULATION OF THE STEMMING

Stemming distance refers to the top portion of the blasthole normally filled with inert material to confine the explosive gases. In order that a high explosive charge functions properly and releases the maximum energy, the charge must be confined in the borehole. Adequate confinement is also necessary to control airblast and flyrock. The common relationship for stemming determination on land is:

$$T = 0.7 \times B$$

where:

T = Stemming (ft)
B = Burden (ft)

In most cases, a stemming distance of 0.7 times burden is adequate to keep material from ejecting prematurely from the hole. It must be remembered that stemming distance is proportional to the burden, therefore, charge diameter, specific gravity of explosive and specific gravity of rock were all needed to determine the burden, and stemming distance is also a function of these variables. If the blast is poorly designed, a stemming distance equal 0.7 x B may not be adequate to keep the stemming from blowing out. In fact, under conditions of poor design doubling, tripling and quadrupling the stemming distance may not ensure the holes will function properly, therefore, the average stemming distance previously discussed is only valid if the shot is functioning properly.

Example 4.2

In example 4.1, a 3 inch diameter blasthole was used in limestone. It was determined that a 6.25 feet burden would be a good first approximation. To determine the stemming distance needed in that blast:

$$T = 0.7 \times B \quad \text{(For crushed stone or drilling chips)}$$

$$T = 0.7 \times 6.25 = 4.38 \text{ ft}$$

where:

T = Stemming (ft)
B = Burden (ft)

The common material used for stemming is drill cuttings, since they are conveniently located at the collar of the blasthole. However, very fine cuttings commonly called drilling dust make poor stemming material. If one uses drill cuttings heavy with drilling dust, approximately 30% or 0.3 x B more stemming would have to be used than if the crushed stone were used for the stemming material. In instances where solid rock is located near the surface of the bench (cap rock), operators often bring the main explosive column as high as possible to break this massive zone. However, they do not want to risk the possibility of blow-out, flyrock and airblast. In cases such as this, it is common to bring crushed stone to the job site to use as stemming material. In example 4.2, where the stemming distance was calculated, if drilling dust were used instead of crushed stone or drilling chips, it may be necessary to increase the stemming depth to equal burden distance. Drilling dust makes poor stemming material since it will not lock into borehole walls and is easily ejected.

If stemming distances are excessive, poor top breakage will result and the amount of backbreak will increase. When a blast functions properly, the stemming zone will gently lift and slowly drop onto the broken rock pile after the burden has moved out. This action is illustrated in Figure 4.10.

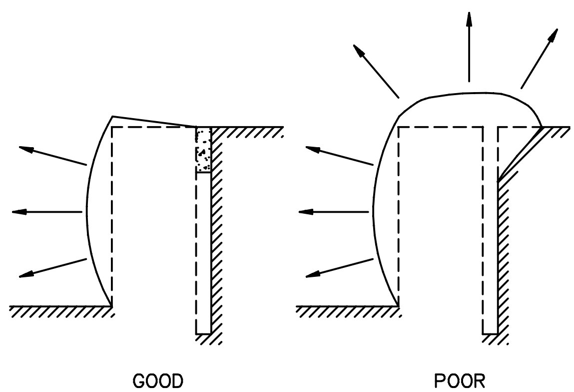


Figure 4.10 Stemming Zone Performance

Stemming in Underwater Blasting

For underwater blasting, in 40 feet of water, the relationship becomes

$$T = 0.2 \times B$$

where:

T = Stemming (ft)
B = Burden (ft)

Selection of the proper size of stemming material in underwater blastingis important if one wants to minimize the stemming depth in order to break cap rock. Very fine drilling dust will not hold into the blasthole. Very coarse materials have the tendency to bridge the hole when loading and may be ejected like golf balls. The optimum size of stemming material for stemming blastholes would be 0.5 to 0.75 inches in diameter clean crushed stone.

Upon detonation of the explosive in the blasthole, stemming particles will be compressed to mortar consistency for a short distance above the charge (Figure 4.11).

Figure 4.11A Stemming Material Compaction Immediately Above Charge. Compact Material Results from Crushed Stone (on the left)

Figure 4.11B Stemming Material Compaction Immediately Above Charge In Borehole

STEMMING PLUGS

Stemming plugs are either used to retain the stemming at a specific location in the blasthole or to channel the forces from a blast in a specific manner into the stemming material. The plugs that hold the stemming in a particular location in a blasthole are normally made of polyethylene shells, gas bags or polyurethane foam plugs. These plugs can be used to support charges or stemming in the blasthole or to support the stemming above a charge or air gap in the blasthole.

The plugs that are made to channel forces into the stemming are normally either conical or spherical in shape (Figure 4.12). These plugs are placed into the stemming zone with the intent of causing the stemming material to bridge and lock into the blasthole walls more efficiently as gas pressure from the detonating explosive exerts force against the plug. It is claimed that these plugs will reduce the amount of stemming needed or will eliminate blow out or stemming ejection from the blasthole. These devices seem to be effective in underground rounds or where poor quality stemming materials such as drill cuttings are used. I have seen no definitive data that they are more effective in situations where the proper crushed stone stemming is employed under the same blasting circumstances.

Figure 4.12 Plugs To Channel Forces Into Stemming

SUBDRILLING

Subdrilling is a common term to denote the depth which a blasthole will be drilled below the proposed grade to ensure that breakage will occur to the grade line. Blastholes normally do not break to full depth. On most construction projects, subdrilling is used unless, by coincidence, there is either a soft seam or a bedding plane located at the grade line. If this occurs, no subdrilling would be used. In fact, blastholes may be back filled a distance of 6 to 12 charge diameters to confine the gasses and keep them away from a soft seam (Figure 4.13). On the other hand, if there is a soft seam located a short distance above the grade line and below there exists massive material, it is not uncommon to have to subdrill considerably deeper in order to break the material below the soft seam. As an example, Figure 4.14 indicates a soft seam one foot above the grade. In this case, a subdrilling approximately equal to the burden distance was required below the grade to ensure breakage to grade. In most instances on land, subdrilling is approximated as follows:

$$J = 0.3 \times B$$

where:

J = Subdrilling (ft)

B = Burden (ft)

Subdrilling Underwater

In most instances underwater, subdrilling is approximated as follows:

$$J = 0.5 \times B \text{ to } 0.7 \times B$$

where:

J = Subdrilling (ft)
B = Burden (ft)

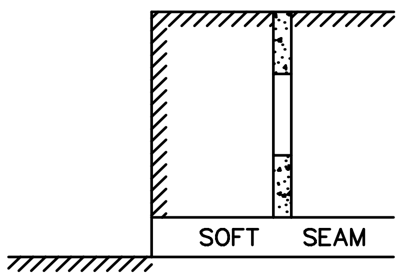


Figure 4.13 Backfill Borehole to Soft Seam

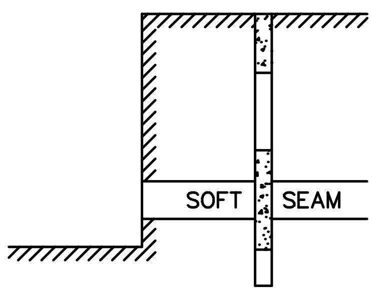


Figure 4.14 Problems of Soft Seam Off Bottom

The subdrilling must not contain drill cuttings, mud or any rock materials. If borehole walls naturally slough and fill in, drilling must be deeper than the subdrilling previously discussed so that at the time of loading the calculated amount of subdrilling is open and will contain explosives.

In order to get a flat bottom in an excavation, it makes good economic sense to drill to a depth below grade, which ensures, in spite of random drilling depth errors and sloughing holes, that all hole bottoms will be down to the proper depth at the time of loading. If drilling is done slightly deeper than required and some holes are too deep at the time of loading, the blaster can always place drill cuttings in the bottom of those holes to bring them up to the desired height. The blaster, however, does not have the ability, at the time of loading, to remove excessive cuttings or material that has fallen into the hole.

The function of subdrilling is illustrated in Figure 4.15. The lines on the figure represent stress contours or zones where the stresses in the rock are equal. The zone that is cross-hatched indicated the zone of maximum tension in the rock. In Figure 6.7, where subdrilling was used, there is a larger zone of maximum tension and it occurs closer to floor level or the area that must be sheared.

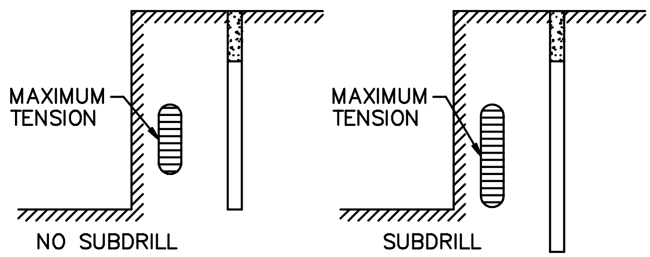


Figure 4.15 Subdrilling and Maximum Tensile Stress Levels

BREAKAGE BELOW BLASTHOLES

There are often concerns that blasting will cause breakage of the formation below the blast area and possibly damage aquifers. The damage below a blast is minimal. Research that has been conducted by Konya has shown that the explosives charges work laterally, perpendicular to the axis of the blasthole and produce a minimum amount of breakage below a blasthole.

The breakage is normally only a few feet at maximum in homogenous rock and less if the material has bedding planes. The naturally occurring bedding planes function in a similar manner to presplitting. Cracks are stopped by the bedding planes and have insufficient energy to start growing on the other side of the bedding plane (Figure 4.16).

In general one could assume that homogenous rock will be undamaged at a distance below a blast equivalent to six inches in depth for every inch of blasthole diameter. For example a six inch diameter blasthole would not damage rock more than 36 inches below the bottom of the blasthole.

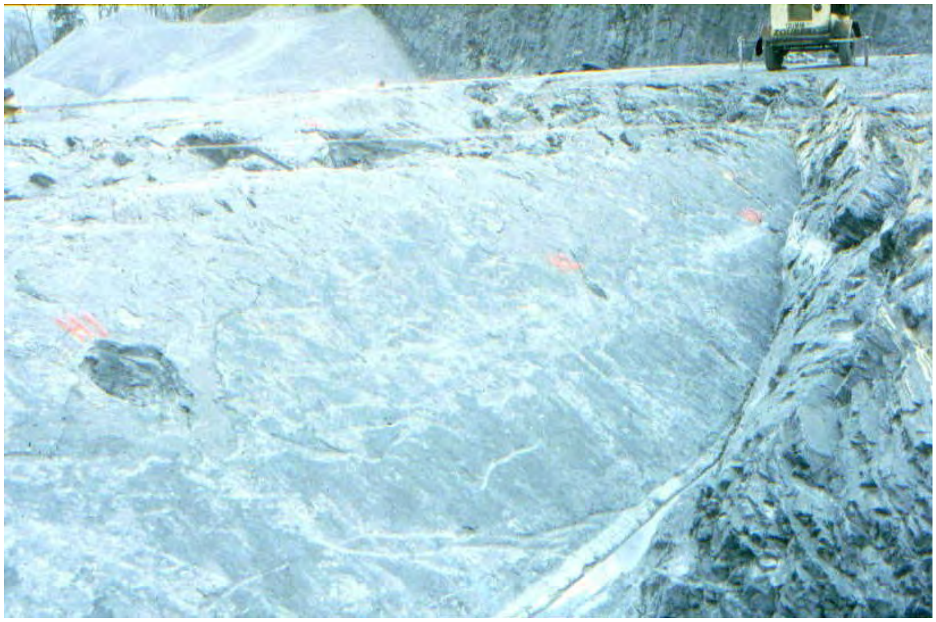


Figure 4.16 Breakage Below Blastholes

5. TIMING EFFECTS ON FRAGMENTATION

Selection of the proper initiation timing is every bit as important as the selection of the proper physical dimension, such as burden and spacing. Two general conditions of initiation timing will be discussed. The first is where holes within a row are fired instantaneously or simultaneously. Simultaneous initiation along a row does mandate a larger spacing and therefore, since holes are spaced further apart, the cost per yard or per ton of the broken material is reduced. The drawbacks of having simultaneous initiation along a row, of course, are problems that would arise due to ground vibration or having many holes firing at the same time. Although more yardage is produced by instantaneous initiation, the fragments would be coarser than that produced by proper delay initiation timing with shorter spacings. Delay initiation timing along a row does reduce ground vibration and produce finer fragmentation at elevated cost. Some relatively simple rules on delay initiation timing hole-to-hole are as follows. Table 5.1 supplies time constants for various rock types. The information in this table can be used along with the equation 6.8.

TABLE 5.1 TIME DELAY BETWEEN BLASTHOLES (FOR 2 FREE FACES)

ROCK TYPE	T_H CONSTANT (ms/ft)
Sands, loams, marls, coals	1.8 - 2.1
Some Limestone, rock salt, some shales	1.5 - 1.8
Compact limestone and marble, some granites and basalts, quartzite rocks, some gneisses and gabbroe	1.2 - 1.5
Biabase, diabase porphyrites, Compact gneisses and micashists, magnetites	0.9 - 1.2

HOLE-TO-HOLE DELAYS

$$t_H = T_H \times S$$

where:

t_H	=	Hole-to-hole delay (ms)
T_H	=	Delay constant hole-to-hole from Table 5.1
S	=	Spacing (ft)

ROW-TO-ROW DELAYS

Guidelines for row-to-row initiation are as follows:

a) Short delay times cause higher rock piles closer to the face.
b) Short delay times cause more endbreak.
c) Short delay times cause more violence, airblast and ground vibration.
d) Short delay times have more potential for flyrock.
e) Long delay times decrease levels of ground vibration.
f) Long delay times decrease the amount of backbreak.

To determine the delay time to be used between rows in production blasts, the general guidelines are given in Table 5.2A.

TABLE 5.2A TIME DELAY BETWEEN ROWS

T_R CONSTANT (ms/ft)	RESULT
2	Violent excessive airblast, backbreak, etc.
2-3	High pile close to face, moderate airblast, backbreak
3-4	Average pile height, average airblast and backbreak
4-6	Scattered pile with minimum backbreak

Delayed times should not be less than two milliseconds per foot of burden between rows. Delay times should normally be no greater than 6 milliseconds per foot of burden between rows. When wall control is critical in multi-row shots (6 or more rows), row-to-row delays may be expanded to as much as 10-20 ms/ft. of burden to obtain low muck piles. An equation for delay time between rows is as follows:

$$t_r = T_R \times B$$

where:

t_r	=	Time delay between rows (ms)
T_R	=	Time factor between rows
B	=	Burden (ft)

The selection of an approximate time in milliseconds is found by determining a time factor using Tables 6.5 and 6.6A and making one multiplication. The values obtained may be difficult if not impossible to implement in the field because of the limitations in hardware available from the manufacturers. Obtaining accurate time is critical. The following section will illustrate methods of determining the time and using different initiation systems available to meet those times as closely as possible.

A significant portion of the problems, which result from blasting and cause airblast, flyrock, excessive vibration and poor fragmentation, are directly related to the initiation timing (Figure 4.17). Table 5.1 and Table 5.2A produce initiation timing values, which could be used to determine performance characteristics of timing. However, timing must also be considered for its potential to cause ground vibration.

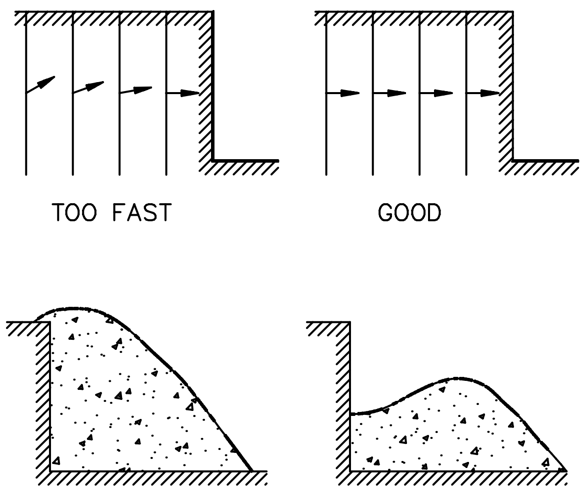


Figure 4.17 Piling and Uplift Resulting from Timing

It is generally proposed by various regulatory agencies that charges be fired on an 8 millisecond or more delay if they are to be considered independent events from the standpoint of ground vibration. Both the vibration character and the blasting performance time previously discussed must be looked at from a realistic standpoint.

CALCULATION OF POWER FACTOR

Calculation of powder factor requires the calculation of the explosives charges in the blast and the volume of rock broken in cubic yards. The powder factor is the explosive load divided by the cubic yards broken per blasthole. Although the amount of explosive in the subdrill is calculated as explosive used in the blasthole the volume of the rock below grade which is not excavated is not considered. The calculation of the amount of explosives in the blasthole is:

$$EXP = 0.3405 \; SGe \; De^{2} \; (L + J - T)$$

where:

EXP	=	Explosive weight (lbs)
SGe	=	Specific gravity of the explosive
De	=	Diameter of the explosive (in)
L	=	Bench height (ft)
J	=	Subdrill depth below grade (ft)
T	=	Stemming length (ft)

The calculation of the cubic yards blasted per blasthole is:

$$yd^3 = B\ S\ L / 27$$

where:

yd^3	=	Cubic yards
B	=	Burden (ft)
S	=	Spacing (ft)
L	=	Bench height (ft)

6. BLAST VIBRATION

VIBRATION AND SEISMIC WAVES

SEISMIC WAVES

Seismic waves are waves that travel through the earth. These waves represent the transmission of energy through the solid earth. Other types of wave transmission of energy are sound waves, light waves, and radio waves. Earthquakes generate seismic waves. The science that studies earthquakes is Seismology, the name being derived from the Greek word ***seismos*** meaning to shake. In addition to the naturally generated seismic waves, there are many man made sources of seismic waves. When these men made seismic waves are sensible, that is when they can be felt, and they are referred to as "vibration".

For some time now there has been a "Vibration Problem." What this means is that some of man's activities such as blasting, pile driving, etc., produce seismic waves which people can feel. They are disturbed, concerned, perhaps fearful, and begin inquiring about what is happening. Thus begins a confrontation know as the "Vibration Problem."

The vibration problem has been thoroughly investigated in the past and continues to be the subject of ongoing research. Since the subject starts with seismic energy and seismic waves, a brief discussion of these waves is in order.

Seismic waves are divided into two large classes, body waves and surface waves.

BODY WAVES

Body waves travel through the mass of the rock, penetrating down into the interior of the rock mass. There are two kinds of body waves: compressional waves and shear waves. The compressional wave is a push-pull type wave that produces alternating compression and dilatation in the direction of wave travel, such as occurs in a stretched spring. The shear wave is a transverse wave that vibrates at right angles to the direction of wave travel. The motion of a shear wave can be seen in a rope that is strongly flexed at one end. The rope moves up and down, but the wave travels outward toward the other end. Liquids do not transmit shear waves.

SURFACE WAVES

Surface waves travel over the surface of rock mass but do not travel through it. The depth to which the rock mass is affected by the wave motion is approximately one wavelength. Surface waves are generated by body waves that are restrained by physical and geometrical conditions from traveling into the interior of the rock mass. Surface waves produce the largest ground motions and are the large energy carriers.

A schematic representation of the motion for compressional waves and shear waves is shown in Figures 6.1 and 6.2.

CAUSES OF SEISMIC WAVES

Seismic waves are elastic waves. Elasticity is a property of matter that causes a material to regain its original shape or size if it is deformed. A very familiar example of elastic behavior is that of a stretched rubber band that springs back to its original length when released. Rock materials are highly elastic and thus produce strong elastic or seismic waves when deformed. Deformation occurs in two ways, a change in volume that is a compression or in shape that is a shear.
Materials resist deformation and this resistance is called an elastic modulus. If the deformation is a compression, the resistance is measured by modulus of incompressibility or the bulk modulus. If the deformation is a shear, the resistance is measured by the modulus of rigidity or the shear modulus. Thus, there are the two types of seismic waves, compressional and shear.

Operations such as blasting will always produce vibration or seismic waves. The reason for this is quite simple. The purpose of blasting and other such operations is to fracture rock. This requires an amount of energy sufficient to exceed the strength of the rock or exceed the elastic limit. When this occurs, the rock fractures. As fracturing continues, the energy is used up and eventually falls to a level less than the strength of the rock and fracturing stops. The remaining energy will pass through the rock, deforming it but not fracturing it because it is within the elastic limit. This will result in the generation of seismic waves. A simple schematic representation of compression and shear is shown in Figures 10.3 and 10.4.

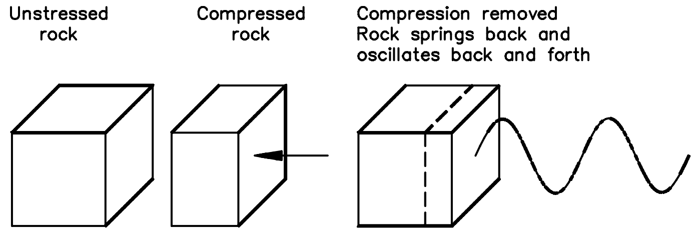


Figure 6.1 Deformation by Compression

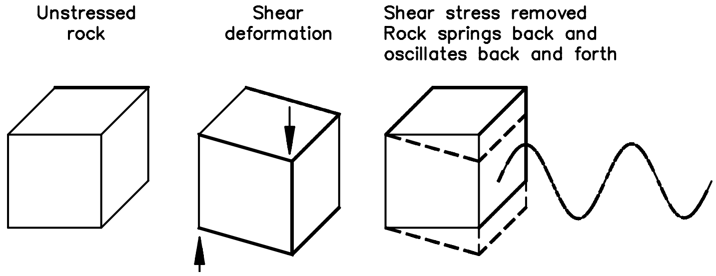


Figure 6.2 Deformation of Shear

WAVE PARAMETERS

The fundamental properties that describe wave motion are called wave parameters. These are measured and quantified when discussing wave motion or vibration. Consider the simple harmonic wave motion illustrated in Figure 6.3 and represented by the equation:

$$y = A \sin(\varpi t)$$

where:

y	=	Displacement at any time t, measured from the zero line or time axis
t	=	Time
A	=	Amplitude or maximum value of y
ϖ	=	$2 \pi f$
T	=	Period or time for one complete oscillation or cycle
f	=	Frequency, the number of vibrations or oscillations occurring in one second, designated Hertz, Hz

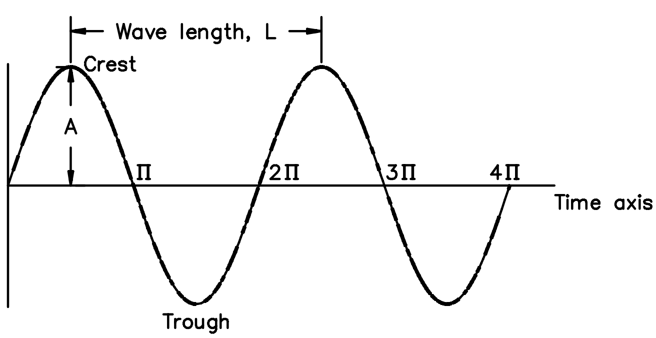


Figure 6.3 Wave Motion And Parameters

Period and frequency are reciprocals so that:

$$f = \frac{1}{T} \quad \text{or} \quad T = \frac{1}{f}$$

Wavelength L is the distance from crest to crest or trough to trough measured in feet and is equal to the wave period multiplied by the propagation velocity V.

$$L = V\,T$$

UNDERSTANDING VIBRATION INSTRUMENTATION

SEISMIC SENSOR

The function of vibration instrumentation is to measure and record the motion of the vibrating earth. In basic scientific terms, this is a seismograph comprised of a sensor and recorder.

The sensor is in fact three independent sensor units placed at right angles to each other. One unit is set in the vertical plane, while the remaining two units lie in the horizontal plane at right angles to each other. Each sensor will respond to motion along its axis. Three are necessary to completely determine the ground motion. The three units are enclosed in a case as shown in Figure 6.4.

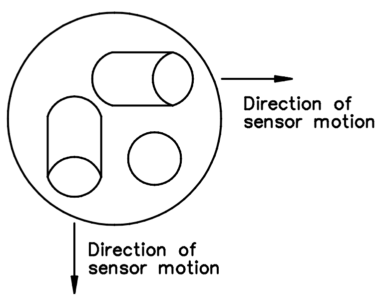


Figure 6.4 Seismograph Sensor

The configuration of the sensor case varies with the manufacturer, and may be round, square, rectangular, or triangular.

The sensor is usually an electromagnetic transducer that converts ground motion into electrical voltage. Inside the sensor is a coil of wire suspended in a permanent magnet field. The magnet is attached to the sensor case and cannot move, but the coil suspended in the magnetic field by springs or hinges is free to move. Any movement of the coil relative to the magnetic field will generate an electrical voltage proportional to the speed of the coil movement. If the coil moves slowly, a small voltage is generated. If the coil moves fast, a large voltage is generated. When the ground vibrates, the sensor will vibrate, but the suspended coil inside will tend to remain motionless due to its inertia, thus producing relative motion between the coil and the magnetic field, resulting in the generation of an electrical voltage.

A schematic diagram of the sensor transducer is shown in Figure 6.5.

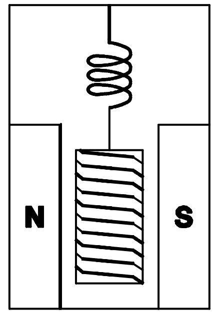


Figure 6.5 Sensor Mechanism

The recorder takes the voltage output of the sensor, converts it back into motion, and produces a visual record of the ground motion. Since the sensor consists of three mutually perpendicular independent units, there will be three traces on the record, one for each sensor unit. This record is then ready for analysis and interpretation.

The recorder changes the output voltage of the sensor into motion by use of a galvanometer. When a voltage is generated at the sensor, a current will flow through the circuit causing the galvanometer coil to move. Thus the electrical energy has been changed back into motion and may be amplified in the process. The recorder also puts timing lines and calibration signals on the record. Finally, the recording of the motion may be done photographically or by heat stylus.

The ground motion may also be recorded on magnetic tape. To obtain a record from magnetic tape, it is necessary to have a playback system and a chart recorder. This system is somewhat more involved, but adds increased flexibility. The tape can be played back at different amplifications or for varied analysis techniques. In addition, many events (i.e., blasts) can be recorded on a single magnetic tape. Tape cassettes are inexpensive and easily available.

SEISMOGRAPH SYSTEMS

There are many seismograph systems, or simply seismographs, available today, each of which performs the basic function of measuring ground motion. The many variations are a response to needs, constraints, and advancing technology. A brief description of the main types of seismographs will be helpful.

Analog seismograph - a three component system that produces a record of the ground motion. It is called analog because the record is an exact reproduction of the ground motion only changed in size, amplified, or de-amplified.

Tape seismograph - the same as the analog seismograph, except that it records on a magnetic tape cassette instead of producing a graphic record. A record of the ground motion is obtained by use of a playback systems and a chart recorder.

Vector sum seismograph - the standard seismograph system consists of three mutually perpendicular components. The resultant ground motion can be determined by combining the components using the relationship:

$$R = \sqrt{V^2 + L^2 + T^2}$$

where:

R	=	Resultant motion
V	=	Vertical component of motion
L	=	Longitudinal component of motion
T	=	Transverse component of motion

The vector sum seismograph performs this mathematical calculation electronically; that is, it squares the value of each of the components for each instant of time, adds them, and takes the square root of the sum. It then produces a record of the vector sum.

Bar graph seismograph - a three component system that differs in its recording system. Instead of recording the waveform of the ground motion at each instant of time, only the maximum ground motion of three components is recorded as a single deflection or bar whose magnitude can be read from the record graph. This is a very slow speed recording system which can be put in place and left to record for periods up to thirty or sixty days.

Triggered seismograph - an analog or tape seismograph that automatically starts to record when the ground vibration level reaches a predetermined set value, which triggers the system.

Most seismographs are equipped with meters or displays that register and hold the maximum value of the vibration components and the sound level. Other seismographs are equipped to produce a printout that gives a variety of information such as maximum values for each vibration component, frequency of vibration for the maximum value, vector sum, and sound level. Blast information such as date, blast number, time, location, job designation, and other pertinent information can also be added to the printout.

VBRATION PARAMETERS

Wave parameters were discussed earlier. Vibration parameters are the fundamental properties of motion used to describe the character of the ground motion. These are displacement, velocity, acceleration and frequency. As a seismic wave passes through rock, the rock particles vibrate, or are moved from the rest position. This is displacement. When the particle is displaced and moves, it then has velocity and can exert force that is proportional to the particle's acceleration. These fundamental vibration parameters are defined here:

Displacement - The distance that a rock particle moves from its rest position. It is measured in fractions of an inch, usually thousandths.

Velocity - The speed at which the rock particle moves when it leaves its rest position. It starts at zero, rises to a maximum, and returns to zero. Particle velocity is measured in inches per second.

Acceleration - The rate at which particle velocity changes. Force exerted by the vibrating particle is proportional to the particle acceleration. Acceleration is measured in fractions of "g", the acceleration of gravity.

Frequency - The number of vibrations or oscillations occurring in one second, designated Hertz (Hz).

Vibration seismographs normally measure particle velocity since the standards of damage are based on particle velocity. There are, however, displacement seismographs and acceleration seismographs. Also, velocity seismographs can be equipped to electronically integrate or differentiate the velocity signals to produce a displacement or acceleration record.

STANDARDS DEVELOPMENT

RECENT DAMAGE CRITERIA

In 1980, the U.S. Bureau of Mines reported on its most recent investigation of surface mine blasting in R.I. 8507 (Siskind, et al). Structural resonance responding to low frequency ground vibration, resulting in increased displacement and strain, was found to be a serious problem.

This reintroduced the dependence of damage on frequency. Prior to this, the safe limit particle velocity was independent of frequency. Also, measurements were made inside structures rather than just by ground measurements. Inside measurement seems quite reasonable and logical, but data from previous investigations of structural vibration yielded very poor results, hence, the emphasis on ground measurement.

The threshold of damage used in RI 8507 was specified as cosmetic damage of the most superficial type, of interior cracking that develops in all homes, independent of blasting.

The safe vibration level was defined as levels unlikely to produce interior cracking or other damages in residences.

Safe vibration levels as specified in RI 8507 are given in Table 6.1. These criteria are based on a 5% probability of damage.

TABLE 6.1 SAFE PEAK PARTICLE VELOCITY FOR RESIDENTIAL STRUCTURES (RI 8507)

TYPE OF STRUCTURE	f < 40 Hz	f > 40 Hz
Modern homes - drywall interiors	0.75 in/s	2 in/s
Older homes - plaster on wood lath for interior walls	0.50 in/s	2 in/s

These safe vibration levels represent a conservative approach to damage and have been the subject of intense criticism by the blasting industry.

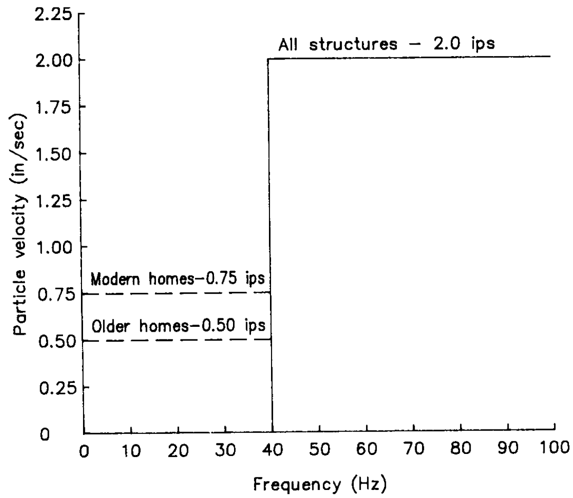


Figure 6.6 Safe Vibration Levels (RI 8507)

ALTERNATIVE BLASTING CRITERIA

RI 8507 also proposed alternative blasting criteria using a combination of displacement and velocity criteria applied over several frequency ranges. These alternative criteria are shown in Figure 6.7.

These criteria using both displacement and velocity over respective frequency ranges have not been accepted by all concerned. Instrumentation will need frequency reading capability in addition to the capability of reading both displacement and velocity in order to cover all ranges. This indicates the state of flux in which the question of safe vibration standards existed, which still exists today.

The problem is associated with the concept of what really constitutes vibration damage. The most superficial type of cracking advocated in RI 8507, while not to be condoned, is scarcely a realistic guide for control. Limiting vibration to a level with a low probability of producing the most superficial type of cracking will cost industry untold millions of dollars. What is the alternative? Damage of this description, if it occurs could be handled through insurance adjustment.

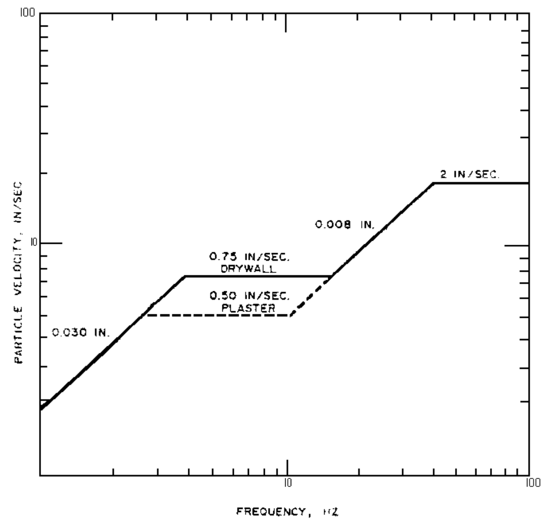


Figure 6.7 Alternative Blasting Level Criteria Source: RI 8507, U.S. Bureau of Mines

An important consideration to be noted is that there probably is no lower limit beyond which damage will not occur, since there will always be structures at the point of failure due to normal environmental stresses. It is not unusual to read of a structure collapsing for no apparent reason.

In RI 8896, (1984), "Effects of Repeated Blasting on a Wood-Frame House" U.S. Bureau of Mines, it indicates that cosmetic cracks occurred during construction of a test house and also during periods when no blasts were detonated. It was further noticed that human activity, temperature, and humidity changes caused strains equivalent to ground particle velocity of 1.2 in/s to 3.0 in/sec.

THE OFFICE OF SURFACE MINING REGULATIONS

The Office of Surface Mining, in preparing its regulations, modified the Bureau of Mines proposed criteria based on counter proposals that it received and came up with a less stringent standard similar to the Bureau of Mines alternative safe blasting criteria. Recognizing a frequency dependence for vibration associated with distance, the Office of Surface Mining Presented its regulation as follows:

TABLE 6.2 OFFICE OF SURFACE MINING, REQUIRED GROUND VIBRATION LIMITS

DISTANCE FROM THE BLASTING SITE (ft)	MAXIMUM ALLOWABLE PEAK PARTICLE VELOCITY (in/s)	SCALED DISTANCE FACTOR TO BE APPLIED WITHOUT SEISMIC MONITORING
0 to 300	1.25	50
301 to 5000	1.00	55
5001 and beyond	0.75	65

This table combines the effects of distance and frequency. At short distances, high frequency vibration predominates. At larger distances, the high frequency vibration has attenuated or died out and low frequency vibration predominates. Buildings have low frequency response characteristics and will resonate and may sustain damage. Therefore, at large distances a lower peak particle velocity, 0.75 in/s, and a larger scaled distance, Ds = 65, are mandated. At the shorter distances, a higher peak particle velocity, 1.25 in/s, and a smaller scaled distance, Ds = 50, are permitted.

The displacement and velocity values and the frequency ranges over which each applies as specified by the Office of Surface Mining are shown in Figure 6.8.

CHARACTERISTIC VIBRATION FREQUENCIES

The Bureau of Mines in RI 8507 distinguished frequencies associated with coal mine blasting, quarry blasting and construction blasting. Coal mine blasting produced the lowest frequencies, quarry blasting was next followed by construction blasting which produced the highest frequencies. This is shown graphically in Figure 6.9.

Although these frequencies are labeled as coal mine, quarry and construction the differences are due to shot size, distance, and rock properties which are characteristic of the operation. Distance is probably the most important factor since low frequency vibration will appear on any blast record if the distance is large enough. High frequency vibration attenuates rapidly because it requires much more energy than low frequency, the energy required varying as the square of the frequency. Thus, low frequency energy propagates to large distances.

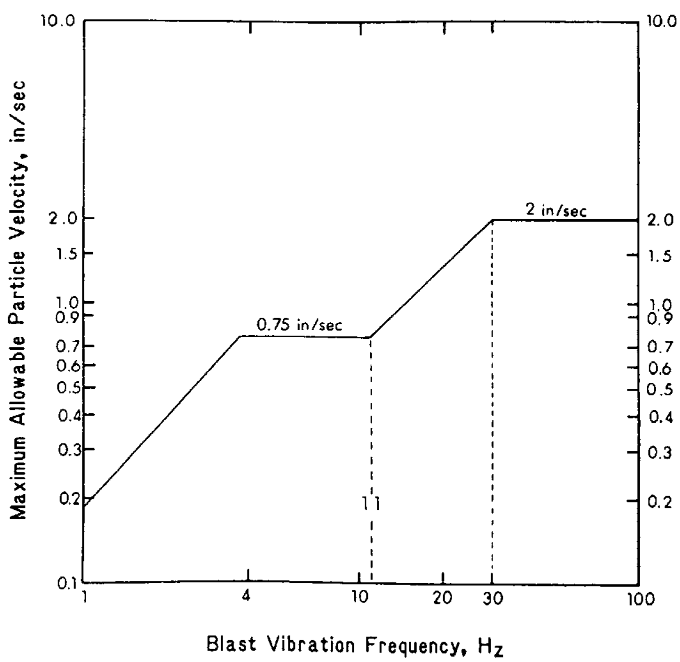


Figure 6.8 OSM Alternative Blasting Level Criteria
(Modified from Figure B 1, RI 8507 U.S. Bureau of Mines)

SPECTRAL ANALYSIS

Spectral analysis is a method for analyzing the frequency content of a vibration record. The record of the ground motion is referred to as a time-domain record. This time-domain record is digitized, usually at one millisecond intervals, after which the digitized data are subjected to a computer performed Fourier Analysis of the blast. The data is now said to be in the frequency domain. It shows the vibration levels associated with each frequency.

Figure 6.10 shows a vibration record in the time-domain and the resulting frequency domain plot after Fourier analysis. This is taken from RI 8168, Siskind, et al, 1976.

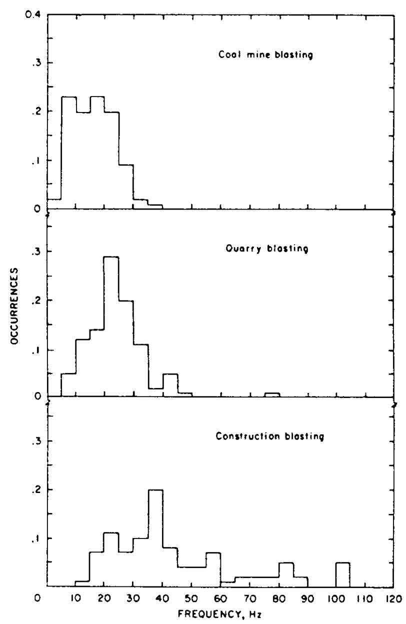


Figure 6.9 Frequencies From Coal Mine, Quarry And Construction Blasting (RI 8507)

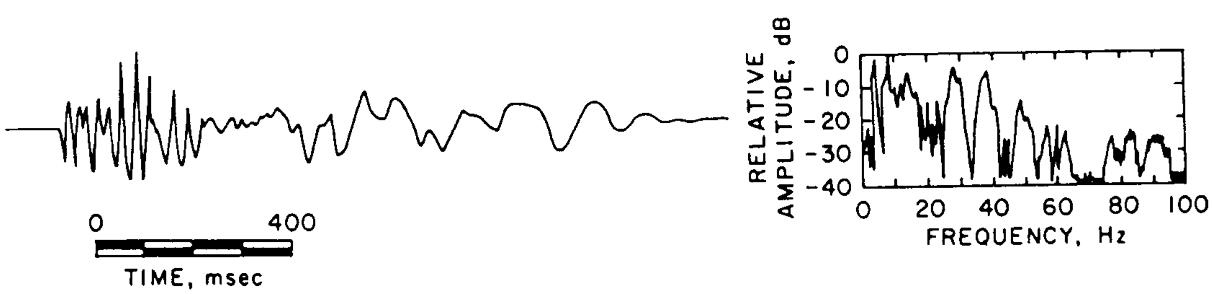


Figure 6.10 Spectral Analysis (RI 8169)

RESPONSE SPECTRA

Response spectra is a methodology in which the response of the structure to a given vibration can be estimated mathematically. Different kinds of blasting generate different frequency spectra. For example, quarry and construction blasting generate higher frequencies than mining blasts. A given structure will respond differently to each of these different frequency generating blasts. Structures also differ, so that two structures may respond differently to the same blast.

A structure is considered as a damped oscillator, with a specific frequency of vibration. The equation of motion of this damped oscillator is programmed into a computer. The digitized data from a blast record is then fed into the computer (impressed on the structure), which calculates the structural response or displacement for each piece of digitized data. The maximum displacement that occurs and the assumed frequency constitute one point (frequency, displacement) of the response-spectra curve.

The process is repeated for additional frequencies and each frequency with its maximum displacement is an additional point for the response spectra curve. When all the frequencies and their maximum displacements have been plotted and the points joined together, the result is the response-spectra curve. This response-spectra curve is a relative displacement curve. It can be converted to a relative velocity response spectra by multiplying by $2\pi f$.

Response spectrum analysis is important because one can estimate the response of a structure to various impressed frequencies, thus anticipating, and hopefully eliminating problems before they arise.

LONG TERM VIBRATION AND FATIGUE

Blasting vibration is a short term phenomenon. The question of repeated blasting effects arises regularly as a point of concern. These could be included with the effects from pile driving and recurring industrial operations. Generally, the effects are relatively low level vibrations, which individually fall below recommended levels of safe vibration and are not considered as potentially damaging.

There is not much information available on this topic, which is generally not regarded as an important problem. Obviously, if it were a significant problem, there would be many damage claims and a general awareness.

One investigation by Walter, 1967, used impact vibration continuously generated in a structure for approximately thirteen months, twenty-four hours a day. The structure was an ordinary room approximately 8 x 8 x 8 feet of dry wall construction. The vibrator was mounted on the ceiling, generating motion that was transmitted throughout the structure and surrounding area.

The natural frequency of the wall panels was 12.5 Hz and the ceiling panel was 60 Hz. Vibration frequencies measured in the wall panels ranged from 10 to 18 Hz. with particle velocity ranging from 0.05 to 0.16 in/s.

The total time of vibration was of the order of thirty million seconds. No noticeable effects resulted from this extended vibration. It was concluded that low level vibration even in the natural frequency response range of the structure has practically zero potential for causing damage.

The U. S. Army Corp. of Engineers, Civil Engineering Research Laboratory, CERL, conducted a fatigue test for the U.S. Bureau of Mines using a biaxial shake table on which was mounted a typical residential room, 8 x 8 x 8 feet. The shake table was programmed with one horizontal component and the vertical component of a quarry blast from Bulletin 656 whose predominant frequencies were 26 and 30 Hz respectively.

Vibration test levels were 0.1, 0.5, 1.0, 2.0, 4.0, 8.0, and 16.0 in/s. Each was run a series of times starting with 1 run, then 5 runs, then 10, 50, 100, and 500 runs with inspection after each series. No damage occurred until the sixth run at 4.0 in/s. This sixth run was preceded by 2669 prior runs with no damage. In fact, there were 666 runs at 2.0 in/s and 5 at 4.0 in/s. with no damage. It is significant to note that when damage occurred it occurred at a particle velocity in excess of 2.0 in/s.

Koerner tested 1/10 scale block masonry walls at resonant frequencies. Failure was observed after approximately 10,000 cycles at particle velocities of 1.2 to 2.0 in/s. Later tests on 1/4 scale block walls showed cracking after 60,000 to 400,000 cycles at particle velocities 1.69 to 1.95 in/s.

These studies show that fatigue effects such as cracking may occur at vibration levels that are relatively high.

VIBRATION EFFECTS

Cracks produced in structures by natural earthquakes, which are low intensity effects, have a characteristic pattern called the X - crack or vibration crack. These cracks result from the fact that the top of a structure, due to its inertia, lags behind. The structure is deformed from a regular rectangular shape into a parallelogram, with one of its diagonals elongated and the other compressed. If the elongation exceeds the strength of the material, it will fail producing a tension crack. As the earth vibration reverses, the same thing will occur in reverse, with the opposite diagonals being elongated and compressed with the possible formation of another tension crack. When both cracks occur they form an X - crack pattern. Figure 6.11 illustrates the process. If it occurs, the X - crack pattern is most likely to be associated with large blasts.

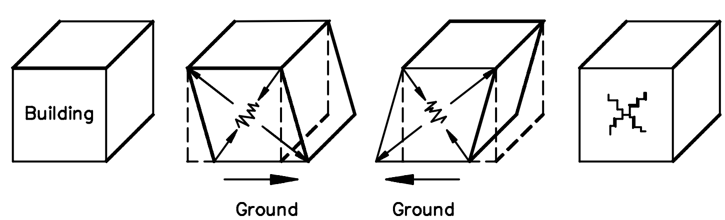


Figure 6.11 Vibration X - Crack Pattern

DIRECTIONAL VIBRATIONAL EFFECTS

The energy that moves out from the source of the blast, measured in terms of ground vibration and peak particle velocity, moves out in all directions from the source. If the ground would transmit vibration in the same manner in all directions and if all other factors remain constant, then theoretically at the same distance in any direction from a blast, the vibration levels would be equal. Unfortunately, on true job conditions, vibration transmission is not ideal and because of changes in the earth structure, vibration is transferred differently in different directions. The geologic structure, joints and faults, will change vibration levels and frequency in different directions of the source. Other factors dealing with blasting pattern design can also contribute to these directional vibration effects.

In the past, it was common practice to monitor behind the blast at the nearest structure since it was assumed that in this direction vibration levels would be greatest. Recommendations for monitoring practice have changed and research has shown that the highest vibration levels are commonly, not behind the shot, but to the sides of the blast. In particular, vibration levels are commonly highest in the direction towards which the delays are progressing. For example, if a blast is fired with the first hole on the left hand side of the pattern and the delays are progressing toward the right hand side of the pattern, then in the direction toward the right hand side of the pattern one would commonly find the highest vibration levels.

In order to calibrate the ground and determine site specific transmission characteristics, it is recommended that at least two seismographs be used when blasting in close proximity to structures. One seismograph placed on the end of the shot and one at 90 degrees. For example, behind the blast. After test shooting is completed and the transmission characteristics are known, the second seismograph may be unnecessary since the ground has already been calibrated and vibration levels in one direction can be related to vibration levels in the other direction.

NON-DAMAGE EFFECTS

Damage producing vibration seldom occurs, but many other effects occur that are disconcerting and alarming to persons who feel and hear the vibration. Some of these effects are:

- Walls and floors vibrate and make noise.
- Pipes and duct work may rattle.
- Loose objects, plates, etc., may rattle.
- Objects may slide over a table or shelf, and may fall off.
- Chandeliers and hanging objects may swing.
- Water may ripple and oscillate.
- Noise inside a structure is greatly amplified over noise outside.
- Vibration is very disturbing to occupants.

CAUSES FOR CRACKS OTHER THAN BLASTING

Cracking is a normal occurrence in the walls and ceilings of structures, and the causes are multiple, ranging from poor construction to normal environmental stress, such as thermal stresses, wind, etc. The Small Home, published by the Architects Small House Service Bureau of the United States, Inc. 1925, gave a list of reasons for the development of cracks, which included the following:

- Building a house on a hill.
- Failure to make the footings wide enough.
- Failure to carry the footings below the frost line.
- Width of footings not made proportional to the loads they carry.
- The posts in the basement not provided with separate footings.
- Failure to provide a base raised above the basement floor line for the setting of wooden posts.
- Not enough cement used in the concrete.
- Dirty sand or gravel used in the concrete.
- Failure to protect beams and sills form rotting through dampness.
- Setting floor joists one end on masonry and the other end on wood.
- Wooden beams used to support masonry over openings.
- Mortar, plaster, or concrete work allowed to freeze before setting.
- Braces omitted in wooden walls.
- Sheathing omitted in wooden walls (excepting in "back- plastered" construction).
- Drainage water from roof not carried away from foundations.
- Floor joists not bridged.
- Supporting posts too small.
- Cross beams too light.
- Sub-flooring omitted.
- Wooden walls not framed so as to equalize shrinkage.
- Poor materials used in plaster.
- Plaster applied too thin.
- Lath placed to close together.
- Lath run behind studs at corners.
- Metal reinforcement omitted in plaster at corners.
- Metal lath omitted where wooden walls join masonry.
- Metal lath omitted on wide expanses of ceiling.
- Plaster applied directly on masonry at chimney stack.
- Plaster applied on lath that is too dry.
- Too much cement in the stucco.
- Stucco not kept wet until set.
- Subsoil drainage not carried away from walls.
- First coat of plaster not properly keyed to backing.
- Floor joists placed too far apart.
- Wood beams spanned too long between posts.
- Failure to use double joists under unsupported partitions.
- Too few nails used.
- Rafters too light or too far apart.
- Failure to erect trusses over wide wooden openings.

- Published in Monthly Service Bulletin 44 of the Architects' Small House Service Bureau of the United States, Inc.

In RI 8896, (1984), "Effects of Repeated Blasting on a Wood-Frame House" U.S. Bureau of Mines, it indicates that cosmetic cracks occurred during construction of a test house and also during periods when no blasts were detonated. It was further noticed that human activity, temperature, and humidity changes caused strains equivalent to ground particle velocity of 1.2 in/s to 3.0 in/sec.

Delay Blasting

Before discussing these techniques, delay blasting should be considered. With the development of the delay cap, particularly millisecond delays, a method came into play by which a large explosive charge could be detonated as a series of small charges, rather than one large charge. Obviously, the reduction in charge size can be made by the use of multiple delays. For example, the use of ten delays would reduce the effective vibration generating charge to one tenth the original charge.

Consider the following example:

A shot consists of 40 holes, 250 lbs. of explosive per hole with a total charge of 10,000 lbs. and is fired instantaneously. The probable vibration level can be calculated at a distance of 1,000 feet.

①①①①①   ①①①①①   ①①①①①   ①①①①①

①①①①①   ①①①①①   ①①①①①   ①①①①①

40 Holes Fired Instantaneously

$$V = 100\left(\frac{1000}{\sqrt{10000}}\right)^{-1.6} = 2.51 \text{ in/s}$$

This is a dangerously high particle velocity, two delays were introduced to reduce the vibration level. This divided the shot into two series or parts of 20 holes each, with 5,000 lbs. per delay.

MS2 ②②②②②   ②②②②②   ②②②②②   ②②②②②

MS1 ①①①①①   ①①①①①   ①①①①①   ①①①①①

20 Holes Fired Per Delay

$$V = 100\left(\frac{1000}{\sqrt{5000}}\right)^{-1.6} = 1.44\,\text{in/s}$$

If two more delays MS3 and MS4 were introduced, reducing the number of holes per delay to 10 and the charge per delay to 2,500 lbs., the probable particle velocity can be calculated.

MS3 ③③③③③ ③③③③③ ④④④④④ ④④④④④ MS4

MS1 ①①①①① ①①①①① ②②②②② ②②②②② MS2

10 Holes Fired Per Delay

$$V = 100\left(\frac{1000}{\sqrt{2500}}\right)^{-1.6} = 0.83\,\text{in/s}$$

Thus a significant reduction in vibration level can be achieved by the use of delays. Why does delay blasting reduce vibration? The answer is fairly simple, but to understand it one must understand the difference between particle velocity and propagation velocity.

METHODS TO ESTIMATE VIBRATION AND DISTANCE FROM BLAST

PROPAGATION LAW

Site Specific Vibration Law

This method involves seismic measurement in addition to calculating the scaled distance values from the blast data.

Data is then plotted on log-log graph paper with particle velocity on the vertical axis and scaled distance on the horizontal axis. To be effective, there must be a spread of data from low to high values. This can be accomplished fairly simple by placing the seismograph at increasingly greater distances on successive shots.

Plot the data on the graph, one point for each particle velocity-scaled distance pair. When all the points are plotted, a straight line or envelope should be drawn on the graph so that all the points are below the line. A reasonably accurate eyeball fit is sufficient (Figure 6.12).

After the data is plotted and the envelope line drawn in, a working value of scaled distance can be read off the graph using this procedure. Start on the particle velocity scale at the specified regulatory particle velocity, e.g., 1.0 in/s. Draw a line horizontally across the graph until it intersects the envelope line. At the point of intersection, drop a vertical line down to the scaled distance axis. The point at which it touches the scaled distance axis is the working value for scaled distance. This value will insure that particle velocities generated by blasting will be less than 1.0 in/s.

If the regulatory value for particle velocity is different from 1.0 in/s, like 2.0 in/s or 0.5 in/s, then start at the proper value and proceed in the same way in Figure 6.12.

TABLE 6.3 VIBRATION DATA

SHOT	DISTANCE (d)	CHARGE WEIGHT (W)	$\sqrt{W}$	SCALED DISTANCE (Ds)	PARTICLE VELOCITY
1	275	406	20.15	13.65	1.74
2	385	348	18.65	20.64	0.72
3	590	291	17.06	34.59	0.34
4	790	286	16.91	46.71	0.21
5	1060	362	19.03	55.71	0.17

The working value for scaled distance read from the graph is Ds = 19. This value can now be used to calculate charge weights and distances that will produce vibration levels less that 1.0 in/s.

For either the average method or the particle velocity-scaled distance method, an on-going addition of data as it occurs should be made. The square dot represents a shot that produced an undesirably high particle velocity due to propagation, cap scatter, bad drilling control, overloading the hole or whatever the cause. The high vibration shows up above the envelope line. Thus, the operator can take immediate steps to control the vibration. Also, a safety factor should be added to the adjusted Ds value. If the adjusted value is 19, then use a value of 23 or 25 as a safety factor.

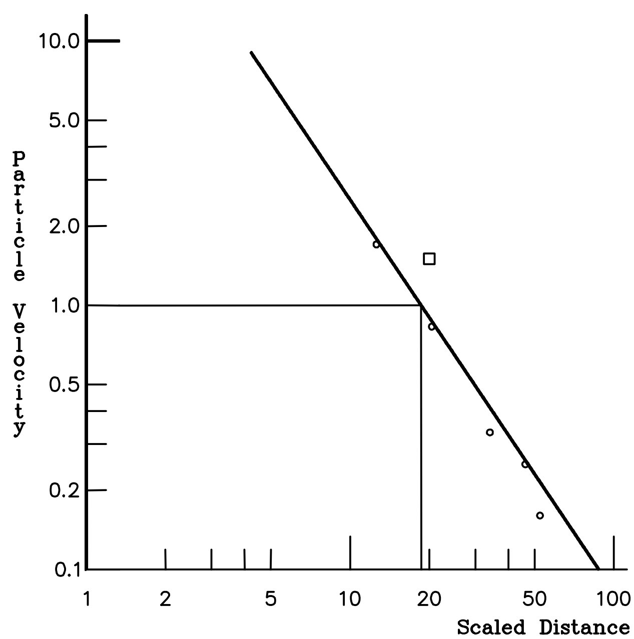


Figure 6.12 Particle Velocity vs. Scaled Distance

Scaled Distance Charts

Scaled distance charts can be made up on log-log graph paper by calculation for given values of the scaled distance. Choosing a scaled distance of 50, one can compute the explosive charge values for various distances. Since the log-log graph is linear, a straight line, it is only necessary to choose two distance values and compute the corresponding charges. The following illustrates the calculation in Table 6.4.

$$Ds = \frac{d}{\sqrt{W}} = 50$$

$$W = \left(\frac{d}{50}\right)^2$$

TABLE 6.4 CHARGE - DISTANCE DATA

DISTANCE (d) (selected) ft	CHARGE WEIGHT (W) (calculated) lbs
50	1
1,000	400

By plotting these pairs of points (50, 1) and (1000, 400) on the log-log graph paper, and connecting them by a straight line, the result is the scaled distance curve for Ds = 50. Additional lines for scaled distance values of 10, 20, 100, or any desired value, can be computed and plotted.

These scale distance curves enable one to graphically determine the permissible explosive charge at any distance for a specified scaled distance value. Figure 6.13 is an example of a scaled distance chart. The chart can be used in the following way. Assume that a scaled distance of 50 is the operational level. What charge is permissible at a distance of 500 feet? Draw a vertical line upward from the distance value 500 until it intersects the Ds = 50 line. Then at the point of intersection on the scaled distance line, draw a horizontal line to the charge weight axis. This point is a value of charge weight, 100 lbs. for the case in question.

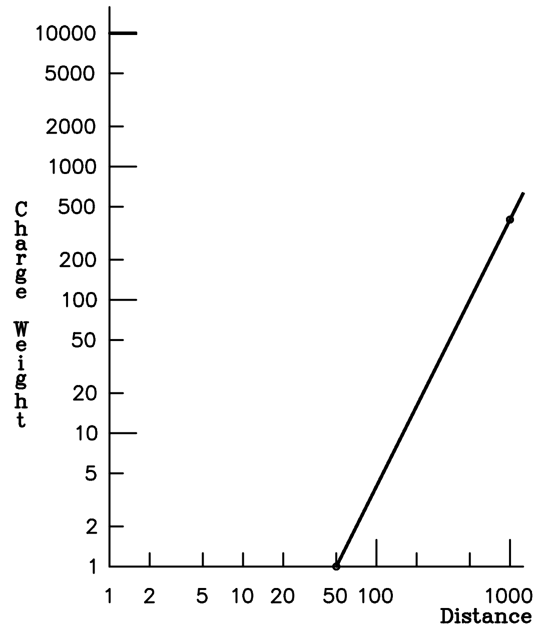


Figure 6.13 Scaled Distance Chart

Ground Calibration

Ground calibration should be done when entering a new area or starting a new project. The two principal factors that affect vibration level are charge weight and distance. In addition, rock type, rock density, presence or absence of rock layering, slope of layers, nature of the terrain, blasthole conditions, presence or absence of water, all combine to influence the transmission of vibration. The simplest way to evaluate these factors is by observation of the vibration levels generated. This is called ground or area calibration.

Ground or area calibration can be accomplished by a scaled distance-particle velocity plot on log-log graph paper using data from a series of blasts as discussed previously. A minimum number of five shots will serve as a starter with more data added as additional shots are fired and recorded. The method synthesizes the many factors affecting vibration transmission and enables the operator to determine a safe working value for the scaled distance. Once the scaled distance is adequately determined, all shots should generate vibration levels less than the corresponding particle velocity

VIBRATION ANALYSIS FROM PORTSMOUTH HARBOR

The following report shows the actual data measured from the underwater harbor deepening project in Portsmouth Harbor.

This rock is primarily granite so the Mean Equation line would be different than one in limestone rock. The reason that this data and equation are shown is to demonstrate that the vibration levels from a blast are very predictable. The cooralation coeficient for the field data is the r^2 value or 91% (Figure 6.14). With the use of the regression analysis 95% confidence level equation one can calculate the expected vibration with different explosive loads and at different distances from the blast (Table 6.5)

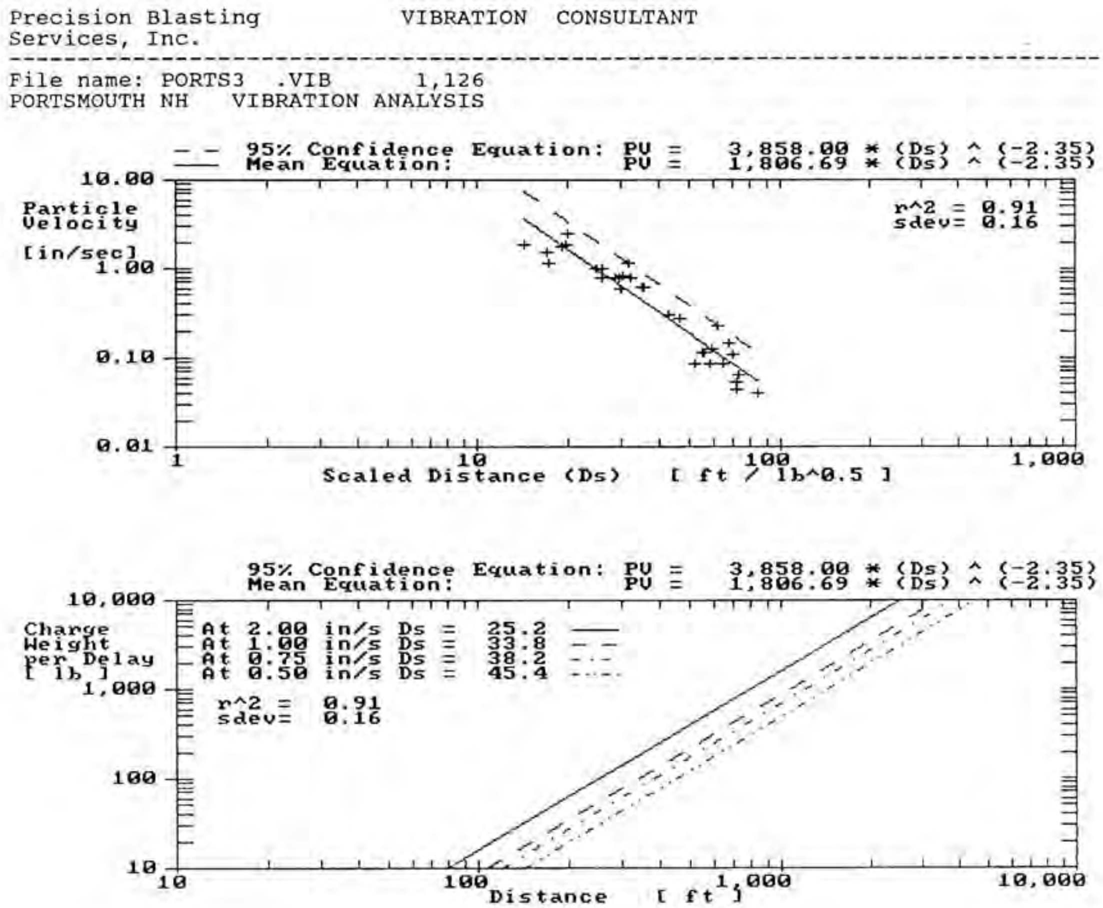


Figure 6.14 Vibration Analysis In Portsmouth Harbor

TABLE 6.5 TYPICAL VIBRATIONS FOR EXPLOSIVE CHARGES IN GRANITE

Exp/Delay	Distance	K	Beta	Vibration	Exp/Delay	Distance	K	Beta	Vibration
5	100	3853	-2.35	0.509	25	100	3853	-2.35	3.376
5	200	3853	-2.35	0.100	25	200	3853	-2.35	0.662
5	300	3853	-2.35	0.039	25	300	3853	-2.35	0.255
5	400	3853	-2.35	0.020	25	400	3853	-2.35	0.130
5	500	3853	-2.35	0.012	25	500	3853	-2.35	0.077
5	600	3853	-2.35	0.008	25	600	3853	-2.35	0.050
5	700	3853	-2.35	0.005	25	700	3853	-2.35	0.035
5	800	3853	-2.35	0.004	25	800	3853	-2.35	0.025
5	900	3853	-2.35	0.003	25	900	3853	-2.35	0.019
5	1000	3853	-2.35	0.002	25	1000	3853	-2.35	0.015
10	100	3853	-2.35	1.150	30	100	3853	-2.35	4.182
10	200	3853	-2.35	0.226	30	200	3853	-2.35	0.820
10	300	3853	-2.35	0.087	30	300	3853	-2.35	0.316
10	400	3853	-2.35	0.044	30	400	3853	-2.35	0.161
10	500	3853	-2.35	0.026	30	500	3853	-2.35	0.095
10	600	3853	-2.35	0.017	30	600	3853	-2.35	0.062
10	700	3853	-2.35	0.012	30	700	3853	-2.35	0.043
10	800	3853	-2.35	0.009	30	800	3853	-2.35	0.032
10	900	3853	-2.35	0.007	30	900	3853	-2.35	0.024
10	1000	3853	-2.35	0.005	30	1000	3853	-2.35	0.019
15	100	3853	-2.35	1.852	35	100	3853	-2.35	5.013
15	200	3853	-2.35	0.363	35	200	3853	-2.35	0.983
15	300	3853	-2.35	0.140	35	300	3853	-2.35	0.379
15	400	3853	-2.35	0.071	35	400	3853	-2.35	0.193
15	500	3853	-2.35	0.042	35	500	3853	-2.35	0.114
15	600	3853	-2.35	0.027	35	600	3853	-2.35	0.074
15	700	3853	-2.35	0.019	35	700	3853	-2.35	0.052
15	800	3853	-2.35	0.014	35	800	3853	-2.35	0.038
15	900	3853	-2.35	0.011	35	900	3853	-2.35	0.029
15	1000	3853	-2.35	0.008	35	1000	3853	-2.35	0.022
20	100	3853	-2.35	2.597	40	100	3853	-2.35	5.864
20	200	3853	-2.35	0.509	40	200	3853	-2.35	1.150
20	300	3853	-2.35	0.196	40	300	3853	-2.35	0.444
20	400	3853	-2.35	0.100	40	400	3853	-2.35	0.226
20	500	3853	-2.35	0.059	40	500	3853	-2.35	0.134
20	600	3853	-2.35	0.039	40	600	3853	-2.35	0.087
20	700	3853	-2.35	0.027	40	700	3853	-2.35	0.061
20	800	3853	-2.35	0.020	40	800	3853	-2.35	0.044
20	900	3853	-2.35	0.015	40	900	3853	-2.35	0.034
20	1000	3853	-2.35	0.012	40	1000	3853	-2.35	0.026

BLASTING NEAR CONCRETE STRUCTURES

On many demolition projects, old concrete is near the blasting operation. In fact, it is not uncommon to blast away part of a structure, leaving the other structure intact. This is a common procedure when locks along rivers need to be refurbished. When locks become eroded due to the water and the environmental conditions, approximately two feet of old concrete is blasted away and new concrete is poured in its place. It is obvious that the concrete that remains from the original structure has been subjected to very high peak particle velocity. Oriard measured values of strain and peak particle velocity that produced various types of failure in concrete. His results are given in Table 6.6.

Blasting vibrations near concrete piers that are made of reinforced concrete would be difficult to damage from Blast vibration. Oriard' data confirms that vibration levels would have to be at extreme levels to cause damage. Rock movement immediately adjacent the piers could possibly cause damage but not from vibration.

TABLE 6.6 FAILURE IN CONCRETE DUE TO VIBRATION

TYPE	STRAIN (µin/in)	PPV (in/s)
Static	140	20
Grout Spall	700	100
Skin Spall	1300	200
Cracking	2400	375

GREEN CONCRETE

Concrete and bridges fall into the high level vibration structures. Green concrete, however, is not in this group. Different types of concrete exist. Therefore, general conservative guidelines for concrete may be given. Since concrete acquires about one third its strength in 72 hours, after this time a peak particle velocity of 1.0 in/s is a reasonable maximum until the concrete reaches full strength at 28 days. Before 72 hours it is not advisable to blast.

BLASTING NEAR GREEN CONCRETE

It is not uncommon to have blasting operations in one section of a project and the pouring of concrete in another. Contractors do have concern as to what effect the blasting vibration has on the integrity of the new structure being poured. Some guidelines for peak particle velocities related to time after pouring are given in Table 6.7.

TABLE 6.7 VIBRATION LEVELS FOR GREEN CONCRETE

TIME AFTER POUR (HOURS)	PPV (in/s)
0 - 4 Hours	2.00
4 - 24 Hours	0.25
1 - 3 Days	1.00
3 - 7 Days	2.00
7 - 10 Days	5.00
> 10 Days	10.00

BRIDGES

Bridges present a variety of sizes, types, construction, age, etc. A steel structure and reinforced concrete structure would minimally be covered by 2.0 in/s and might go to 5.0 in/s. For reinforced concrete bridge piers the limit could be 10 inches per second. The vibration level for reinforced concrete and steel bridges in the FHWA guide blasting specification are 2 to 5 inches per second. The specific value would depend on the age and condition of the bridge.

BURIED PIPELINES

Buried pipelines such as gas and oil transmission lines are normally fabricated of steel, which has a much greater strength than the rock or soil in which it is buried. The primary consideration is that the pipe should be in the elastic zone and never in the fracture zone. This can be accomplished by employing a stand off distance from the blasthole equal to 3 to 5 times the hole spacing. If the hole spacing is 6 foot then the stand off distance is 18 to 30 feet.

MAINFRAME COMPUTER SPECIFICATIONS

Computer specifications are usually frequency dependent changing with the frequency range. One computer manufacturer has the following specifications.

TABLE 6.8 FLOOR VIBRATION

FREQUENCY Hz	DOUBLE AMPLITUDE	ACCELERATION
5-25	0.001 in / 0.0254 mm	
25-100	0.0005 in / 0.0127 mm	
100-300		0.25 g / 2.45 m/s^2

7. HUMAN RESPONSE

SENSITIVITY TO VIBRATION

Human beings are remarkably sensitive to vibration. If this were not so, the vibration problem would scarcely exist. The explosive technology of today insures that most operations are conducted in a safe manner. In relatively few cases is there a significant probability of damage.

Since vibration is felt in practically all cases, the reaction to this sensation is one of curiosity, concern, and even fear. Hence, it is important to understand something about human response to vibration that depends on vibration levels, frequency and duration. In addition to these physical factors, it is important to keep in mind that human response is a highly subjective phenomenon.

Human response has been investigated by many researchers. One of the early investigations was by Reiher and Meister, Berlin, 1931. Other investigations were made by Goldman, 1948, and Wiss and Parmelee, 1974. A composite of these investigators' results was presented graphically in the U. S. Bureau of Mines RI 8507, Siskind, et al, 1980. This composite is represented here in Figure 7.1.

The human response curves are all similar and highly subjective in that the response is a mixture of physiological and psychological factors individual to each person. Based on these curves, a very simple and practical set of human responses can be designated as follows:

TABLE 7.1 HUMAN RESPONSE

RESPONSE	**PARTICLE VELOCITY**	**DISPLACEMENT AT 10 Hz**	**DISPLACEMENT AT 40 Hz**
Noticeable	0.02 in/s	0.00032 in	0.00008 in
Troublesome	0.2 in/s	0.0032 in	0.0008 in
Severe	0.7 in/s	0.011 in	0.0028 in

Vibration is a fact of daily life, which one regularly experiences but is seldom aware of. This type of vibration has been designated Cultural vibration. Generally, it elicits no reaction from the person affected.

Other vibration that contrasts sharply, because it is not part of the daily experience but is unusual, has been designated A-Cultural. It surprises a person, is disturbing, and causes an acute awareness.

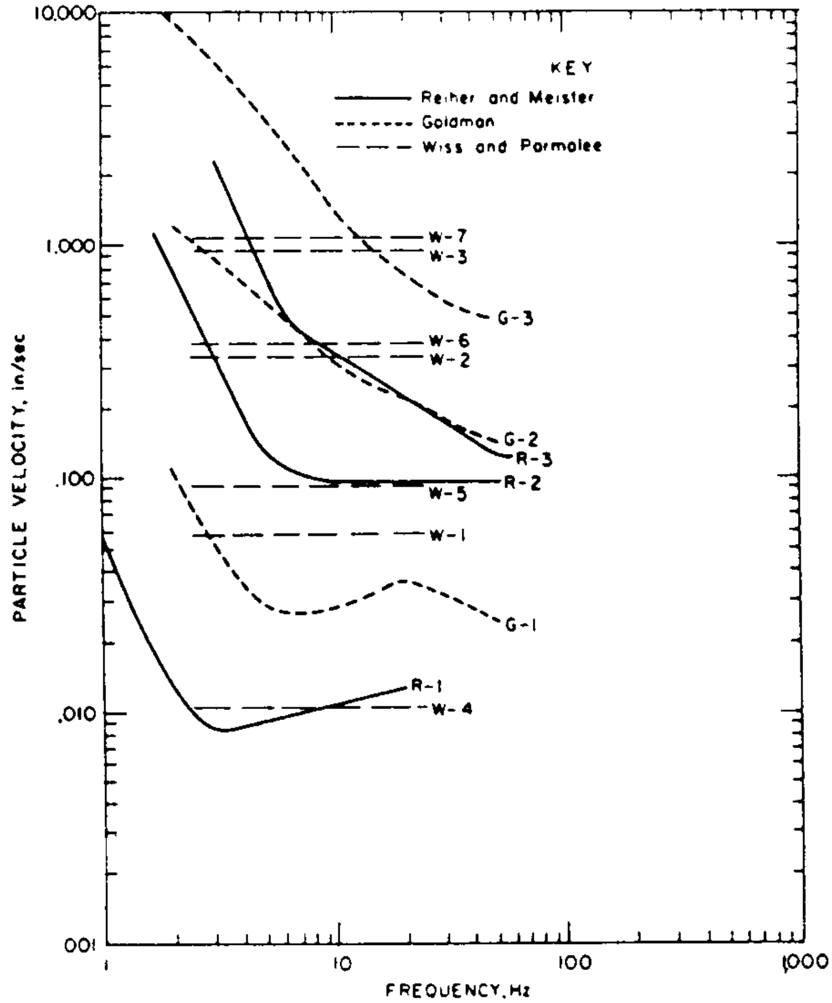


Figure 7.1 Human Response To Vibration (RI 8507)

Some examples of Cultural and A-Cultural vibration are listed in the following:

<u>CULTURAL VIBRATION</u>	<u>A-CULTURAL VIBRATION</u>
Automobile	Blasting
Commuter Train	Pile Driving
Household	Impact Machinery
Industrial Plant or Office	Jack Hammer
Airplane	Forging Hammers
Common Denominator:	Common Denominator:
No reaction	Persons react because these vibrations are unfamiliar, disturbing

Blasting is definitely A-Cultural for the average person. The annoyance and fear associated with it begin at levels much lower that the damage level for structures.

ENVIRONMENTAL VIBRATION

Blast vibrations are sensed by individuals at very low levels. Blasting vibration is A-cultural vibration and because the public equates blasting and explosives with death and destruction rather than progress and improvements in quality of life they are apprehensive about any blasting vibration that they sense.

All activities produce some amount of vibration and are constantly present in homes and structures. Environmental factors such as wind, heating and cooling, changes in humidity, traffic, trains, thunder, fireworks and minor earthquakes all produce stress in a structure. The research conducted by the United States Bureau of Mines showed that strains equivalent to those produced by blast vibrations of three inches per second could result from normal environmental stresses. In most cases the public are either unaware or not concerned by the effects of environmental vibration.

ACTIVITY	SCALE																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
WALKING	X	X	X	X	X															
TRAIN NEARBY	X	X	X	X	X	X														
WALKING ON WOOD FLOOR	X	X	X	X	X	X	X													
PILE DRIVING, PUNCH BARGE	X	X	X	X	X	X	X	X												
GARBAGE DISPOSAL	X	X	X	X	X	X	X	X	X											
JUMPING	X	X	X	X	X	X	X	X	X											
DOOR SLAMS	X	X	X	X	X	X	X	X	X											
POUNDING NAILS	X	X	X	X	X	X	X	X	X	X										
DAILY ENVIRONMENTAL CHANGE	X	X	X	X	X	X	X	X	X	X	X	X								
RIDING IN AUTOMOBILE	X	X	X	X	X	X	X	X	X	X	X	X	X							
PEAK PARTICLE VELOCITY	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.128	0.256	0.512	1.024	2.048	4.096	8.192	16.38	32.77	65.54	131.07	262.14	524.29

Figure 7.2 Konya's Environmental Vibration Scale^{TM}

KONYA'S VIBRATION SCALE

It is often difficult for the public to understand the magnitudes of vibration from blasting and relate this to normal environmental vibration which they sense every day. Since blast vibration is A-cultural and triggers response people become concerned about vibration levels from blasting while they are not concerned about the same vibration levels from cultural vibration which occurs every day in their lives. To put vibration in the proper perspective we can compare both the A-cultural and cultural vibration magnitudes. To do this in a simple understandable manner use the Konya Scale where we can divide the vibration levels into 20 different classes. We can start with a peak particle velocity of 0.001 to less than 0.002 inches per second and put all vibration less than 0.002 in class one. Class one is the level at which some (very few) people can perceive vibration. We then double the previous number from 0.001 to 0.002. Class two vibration would be 0.002 to less than 0.004. Class three would double again to 0.004 but less than 0.008 and so on.

This class method can be used for both blast effects and separately for environmental vibration. The two charts can then be easily compared without confusion. Konya's Blast Effects Scale shows the PPV levels and the class numbers for human perception and potential damage which can result at high vibration levels. Konya's Environmental Vibration Scale shows vibration levels from normal activities.

For example, class five vibration is the level where most people perceive vibration (Konya's Blast Effects Scale) and some become concerned that the vibration will damage their home. Class five on Konya's Environmental Vibration Scale shows that all normal activities on the chart produce vibration at class five or greater. In general most regulatory bodies allow vibration to at least class 10 because they understand that no structural damage can occur in homes at these vibration levels.

EFFECTS	VIBRATION CLASS NUMBER																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PERCEPTION BY OLDER POPULATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PERCEPTION BY ALL					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WATER RIPPLES						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PIPES RATTLE						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LOOSE OBJECTS RATTLE						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CRACK EXTENSIONS IN PLASTER (INVISIBLE)											X	X	X	X	X	X	X	X	X	X
CRACK EXTENSIONS (VISIBLE)												X	X	X	X	X	X	X	X	X
NEW CRACK FORMATION (PLASTER)													X	X	X	X	X	X	X	X
FINE CRACKS IN MASONRY													X	X	X	X	X	X	X	X
BROKEN WINDOWS													X	X	X	X	X	X	X	X
CHIMNEY DAMAGE														X	X	X	X	X	X	X
LARGE CRACKS IN MASONRY WALLS														X	X	X	X	X	X	X
CRACKS IN CONCRETE WALLS																		X	X	X
CRACKS IN CONCRETE SLABS																			X	X
CRACKS IN MASSIVE CONCRETE																				X
PEAK PARTICLE VELOCITY	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.128	0.256	0.512	1.024	2.048	4.096	8.192	16.38	32.77	65.54	131.07	262.14	524.29
IN INCHES/SECOND																				
(THRESHOLD VALUES)																				

Figure 7.3 Konya's Blast Effects Scale ™

8. AIRBLAST

Airblast is an atmospheric pressure wave transmitted from the blast outward into the surrounding area. This pressure wave consists of audible sound that can be heard, and concussion or subaudible sound that cannot be heard. If the pressure of this wave, termed overpressure, is sufficient it can cause damage. Generally airblast is an annoyance problem that does not cause damage but causes unpleasantness between the operator and those affected.

Airblast is generated by the explosive gases being vented to the atmosphere as the rock ruptures, by stemming blow out, by displacement of the rock face, by displacement around the borehole and by ground vibration. Various combinations of these may exist for any given blast.

OVERPRESSURE AND DECIBELS

Airblast overpressure is most commonly measured in decibel (dB). It is also measured in pounds per square inch (psi) The decibel is defined in terms of the overpressure by the equation:

$$dB = 20\log\frac{P}{P_0}$$

where:

dB	=	Sound levels in decibels (dB)
P	=	Overpressure in psi (lbs/in^2)
P_0	=	Overpressure of the lowest sound that can be heard
P_0	=	$2.9 \times 10^{-9} = 3 \times 10^{-9}$ psi (lbs/in^2)

Some typical sound levels with values in both dB and psi are shown in Figure 8.1.

Sound levels are measured on different weighting networks designated A, B, C, and Linear. These differ essentially in the ability to measure low frequency sound. The A-network corresponds most closely to the human ear and discriminates severely against the low frequencies. The B-network discriminates moderately and the C-network only slightly while the Linear network measures all frequencies.

Air Overpressure Compared to Wind Pressure

Wind Equivalent	Standards		
mph	dB	psi	
329.09	180	3	Structural Damage
268.70	176	2	Plaster Cracks
134.35	164	0.5	Windows Break
104.07	160	0.3	
32.91	140	0.03	OSHA Max. 100 Impacts/Day
15.90	128	0.007	US Bureau Of Mines Max.
10.41	120	0.003	OSHA Max. 10,000 Impacts/Day
3.29	100	3×10^{-4}	Pneumatic Hammer
1.04	80	3×10^{-5}	
0.33	60	3×10^{-6}	Conversational Speech
0.10	40	3×10^{-7}	
0.03	20	3×10^{-8}	
0.01	0	3×10^{-9}	Threshold Of Hearing

Figure 8.1 Typical Sound Levels

Sound levels are measured on different weighting networks designated A, B, C, and Linear. These differ essentially in the ability to measure low frequency sound. The A-network corresponds most closely to the human ear and discriminates severely against the low frequencies. The B-network discriminates moderately and the C-network only slightly while the Linear network measures all frequencies.

Sound produced by a blast is primarily low frequency energy and sound measuring devices should have a low frequency response capability to accurately represent the sound levels. A C-weighted network, or preferably a linear-peak, should be used.

Spectral analysis of blast sounds was done by Siskind and Summers, 1974, which clearly showed the very low subaudible frequencies.

GLASS BREAKAGE

Extensive tests were conducted by the U. S. Bureau of Mines and reported in Bulletin 656 to determine the sound levels likely to cause glass breakage, and the scaling law that would apply. Glass breakage occurs at much lower levels of overpressure that structural damage, such as cracking plaster. The absence of glass breakage precludes structural damage. Airblast regulation is keyed to glass breakage.

<u>Bulletin 656 proposed an overpressure of 0.5 psi (164 dB) as a safe level for prevention of glass breakage and indicated that blasting which generated ground vibration below 2 in/s automatically limited air overpressures to safe levels, that is, less that 0.5 psi (164 dB).</u>

Siskind and Summers, Bureau of Mines TPS 78 (1974), proposed safe levels for preventing glass breakage. These levels also helped reduce annoyance. These values are shown in the following table.

TABLE 8.1 SOUND LEVEL LIMITS

	LINEAR PEAK		C-PEAK OR C-FAST	A-PEAK OR A-FAST
	dB	**psi**	**dB**	**dB**
Safe	128	0.007	120	95
Caution	128 to 136	0.007 to 0.018	120 to 130	95 to 115
Limit	136	0.018	130	115
	<u>Recommended</u>		**<u>Not Recommended</u>**	

SCALED DISTANCE FOR AIRBLAST

Airblast is scaled according to the cube root of the charge weight, that is:

$$K = \frac{d}{\sqrt[3]{W}}$$

where:

d	=	Distance (ft)
W	=	Maximum charge weight per delay (lbs)
K	=	Scaled distance value for air overpressure

Recall that vibration is scaled according to the square root of the charge.

$$Ds = \frac{d}{\sqrt{W}}$$

Taking the safe overpressure of 0.007 psi, suggested by Siskind and Summers, and interpolating the airblast scaled distance diagram of Bulletin 656 for this value gives an approximate value for K = 180, or:

$$180 = \frac{d}{\sqrt[3]{W}}$$

This is quite conservative, since it is based on the conservative safe limit value, 0.007 psi. It is derived from quarry blast data and may not apply to other kinds of operations.

REGIONS OF POTENTIAL DAMAGE FOR AIRBLAST

There are two distinct regions of potential airblast damage, which are quite different. They are referred to as Near Field and Far Field.

Near Field

This is the region surrounding the blast site to which there is direct transmission of the pressure pulse. The potential for damage in the near field is small and readily minimized by proper planning. This requires attention to the details of spacing, burden, stemming, explosive charge, delays, covering of detonating cord trunklines and use of cord with minimal core load. Proper execution of these tasks insures a very low probability of glass breakage.

Far Field and Air Blast Focusing

This represents the region far from the blast site (i.e., 4 to 20 miles) where direct transmission cannot account for the effects produced. It represents a focusing or concentration of sound waves in a narrow region. These waves have traveled up into the atmosphere and have been refracted back to the earth, producing an intense overpressure in a narrow focal region.

The cause of airblast focusing is the presence of an atmospheric inversion. The more severe the inversion, the more intense the focusing may be. Wind can also be a significant factor adding to the inversion effect.

ATMOSPHERIC INVERSION

An atmospheric inversion is an abnormal, but not uncommon phenomenon. Normally temperature decreases with height in the atmosphere, cooling at the normal lapse rate of 3.5 °F for each 1,000 feet of height. For example, assume a surface air temperature of 70°F, then under normal lapse rate conditions, the air temperature at 4,000 feet would be:

$$70 - 4\,(3.5) = 56$$

The velocity of sound in air is temperature dependent, increasing as temperature rises and gets warmer or decreasing as temperature falls and gets colder. The change is approximately 1 ft/sec for a temperature change of 1°F. Under normal atmospheric conditions, the air temperature decreases with height so the velocity of sound decreases, causing the sound waves to curve upward away from the ground. The sound is absorbed in the atmosphere. This effect is illustrated in Figure 8.2.

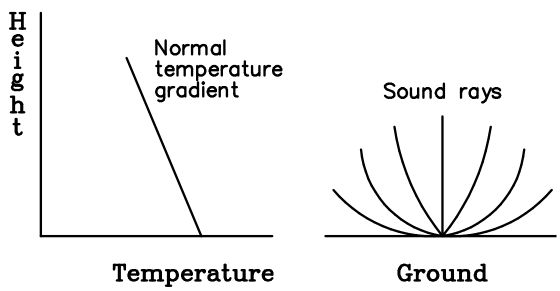


Figure 8.2 Normal Atmospheric Conditions

In an atmospheric inversion, the air temperature increases with height, so the velocity of sound increased, causing the sound waves to curve downward toward the ground. Thus, the sound may return to the earth, but at some distance from its point or origin. Figure 8.3 illustrates the inversion condition and the curving downward of the sound rays in the atmosphere.

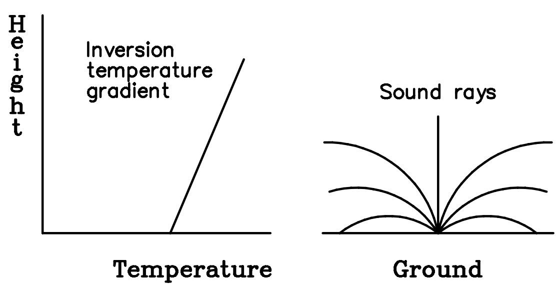


Figure 8.3 Atmospheric Inversion

When the sound returns to the earth as just described, it may under appropriate conditions concentrate or focus in a narrow region and produce much higher sound levels than in adjacent regions on either side. This effect is shown in Figure 8.4.

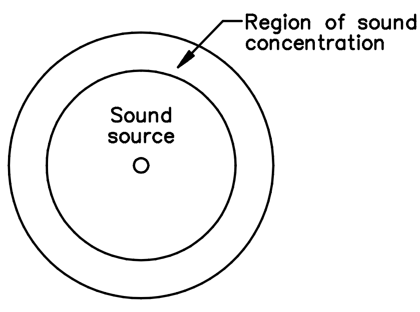


Figure 8.4 Sound Focusing-Inversion Effect

WIND EFFECT

Wind may contribute significantly to causing airblast focusing. On the downwind side, the wind will add to the velocity effect produced by the inversion and increase the sound velocity. On the upwind side, the wind will oppose the velocity effect and decrease the sound velocity. If the wind is strong enough, the sound may be completely blown away from the upwind side. Figure 8.5 shows the wind effect.

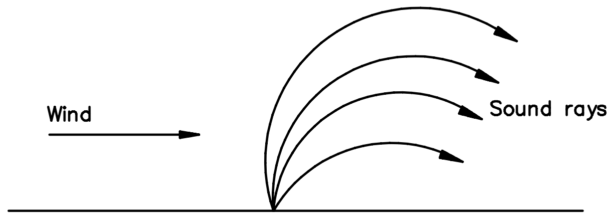


Figure 8.5 Wind Effect

The focal region previously shown as a circular region with sound source at the center may be reduced to a crescent shape by the wind effect, resulting in a higher sound intensity in the focal region. This is shown in Figure 8.6.

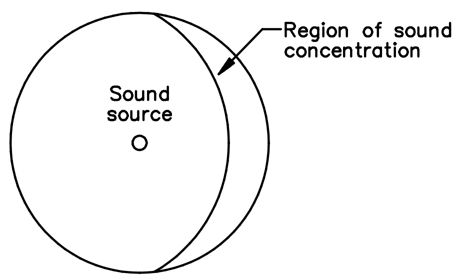


Figure 8.6 Airblast Focusing Plus Wind Effect

Airblast focusing is produced by the combination of an atmospheric temperature inversion and wind. The effect varies with height and must be evaluated at successive elevation (approximately every 1,000 feet). This requires meteorological data and a sophisticated computer program to process it. This is not feasible for normal day to day operations. A diagram of intense airblast focusing is shown in Figure 8.7.

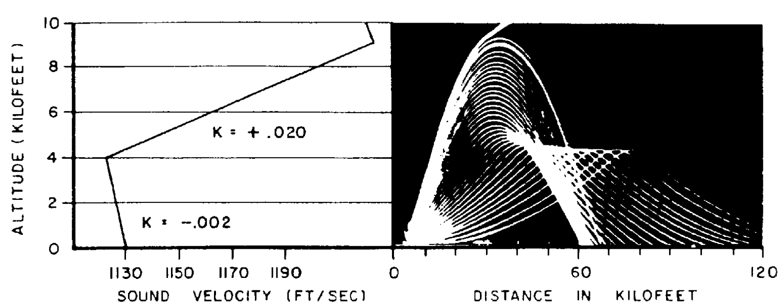


Figure 8.7 Airblast Focusing

AIRBLAST SUMMARY

Little airblast is developed in blasts covered under 40 feet of water. A series of bubbles or on large bubble comes to the surface after the blast is fired (Figure 9.1)

9. VIBRATION AND AIR BLAST MONITORING EQUIPMENT

SEISMOGRAPH SPECIFICATIONS

The newest generation of seismographs should be required that have reproducable results for both high and low frequency events. Units should have a sampling rate of at least 15,000 samples per second and the ability to record for up to 30 seconds per event.

Figure 9.1 Underwater Harbor Deepening Blast at Kill Van Kull

SEISMOGRAPH LOCATIONS

At least six seismographs should be used for blast monitoring on this project. The vibrations should be monitored at buildings or sensitive structures on both sides of the channel and other sensitive locations

10. STRUCTURES OF CONCERN

Residential structures close to the blasting site with either drywall or plaster on lathe would be the weakest structural materials and the ones most likely to show minor damage such as crack extension if blasting levels exceed the limits.

PREBLAST SURVEY INSPECTIONS

Preblast inspections are being mandated more and more by various regulatory agencies, insurance companies and concerned operators.

Purpose

The purpose of a preblast inspection is to document the condition of a structure prior to its exposure to vibration from blasting. Most structures have cracks in various areas that for the most part are not known or only sparsely known to the structure's occupants.

The documentation is useful in a number of ways. First the occupant becomes educated to the fact that there are cracks, the usual reaction is one of surprise. Secondly, the documentation can be used to verify or refute claims of damage resulting from vibration. Since this is so, the preblast inspection must be done carefully and thoroughly.

Cracks in a structure are not static but are dynamic in nature changing from season to season and are affected by a series of factors such as temperature, humidity, wind, soil conditions and overall structural integrity. Assuming reasonably stable soil conditions and structural integrity the diurnal temperature changes produce thermal stresses that may cause cracks to grow in length and width. Similarly the larger seasonal temperature changes, from summer to winter and back, produce significant thermal stresses. In addition, the winter heating season normally causes a drying out of the structure resulting in shrinkage. The process is reversed with spring and summer, when the humidity rises and the structure absorbs moisture and expands.

In general, environmental stresses cause cracks to occur in practically all structures. When blasting vibration occurs, the affected persons examine the premises for possible damage and find the prior existing environmentally produced cracks. The conclusion is automatic, the blasting cause the cracks, when in fact it did not.

PREBLAST SURVEY REPORTS FOR JACKSONVILLE

Thoroughness and care are important in a building inspection. Common sense based on knowledge of what to look for and where to look for it will insure an adequate inspection. The preblast survey report should be an adequate and complete description of what the inspection was able to document. It should be clearly written so that the independent examiner can readily understand what is being reported.

All residential structures immediately adjacent to the channel should be inspected. Some commercial structures that do not generate high vibrations in their business should also be inspected.

Commercial buildings without drywall or blaster on lathe can normally withstand higher vibration levels than residential structures.

11. ENVIRONMENTAL PROTECTION (1983)

MANATEE PROTECTION

The manatee protection program used during the harbor deepening and bridge pier blasting projects in Jacksonville project in the mid-1980's was successful and some elements of this program should be considered in the upcoming project. The program description follows.

Aerial surveys were conducted prior to the beginning of the blasting project. A bell helicopter was used to survey the port area on three consecutive days prior to the beginning of the blasting. Provision 14 of the manatee protection plan stated that if more than five (5) animals were observed on those surveys, the project would be delayed until the number of animals fell below five. The surveys were flown at ground speed, which ranged between 10 kts and 60 kts and at an altitude, which ranged between 50 meters and 200 meters. On the first and third surveys no animals were observed, while on the second survey, three animals were observed. These results permitted blasting to begin on schedule.

DETERMINATION OF THE DANGER ZONE

Various ideas for determining a danger zone for manatees were proposed by members of the U.S. Fish and Wildlife Service and the Florida Department of Natural Resources. Initially it was decided to use a formula proposed by Johnson (1983), Commander (U.S.N.) and Project Manager and Coordinator of OICC TRIDENT.

The danger zone for manatees was delineated by an arc having a radius defined by:

$$D = (13000\ W^{1/3})/P$$

where:

D = radius of the danger zone in feet
W = weight of the explosive charge in pounds
P = overpressure created by the explosion shockwave, where
P = 50 psi + ambient pressure

However, it was later pointed out by Richard Meyers (Great Lakes Dredge and Dock Co.) that this formula could not be applied to the Port Everglades blasting project because it was based on an unconfined blast instead of a confined blast. An unconfined blast is in the air or open water without any physical restrictions, which slow down its development. A confined blast is usually associated with drilling and blasting within the restrictions of rock strata. This formula was subsequently rejected to determine a danger zone for manatees.

Alternatively the physical parameters used by American Dredge Company at an ongoing blasting project at Kings Bay, Georgia, involving confined blasting was used as a basis for determining the danger zone for Port Everglades. The physical parameters of distance vs. overpressure were determined by a test blasting program conducted between 28 June and 2 July 1983. Assuming that a water overpressure of 50 psi or less would not physically harm a manatee, the results of this test program indicated that this overpressure would not be exceeded at an distance of 400 feet given a blast of 780 pounds of explosive per delay.

Since the blasting in Port Everglades would not exceed 600 pounds of explosive per delay, it was decided that 400 feet would be adequate for a manatee danger zone. However, it was also decided to extend the danger zone to 600 feet to ensure a safety margin.

MANATEE PROTECTION PLAN

To adequately ensure the safety of manatees while blasting, a 14 provision plan was developed. Agencies involved in designing this plan included Florida Department of Natural Resources, U.S. Fish and Wildlife Service, U.S. Army Corps, Florida Audubon Society, Port Everglades Authority and Nova University. A complete list of these provisions is provided this report. Only the ones relating the danger zone will be discussed in the text.

VERIFICATION OF MANATEES IN DANGER ZONE

In order to provide dependable verification of the presence of manatees within the blast zone, a detection system was designed which included provisions 7, 8, and 9 of the manatee protection plan.

> Provision 7: A trained observer will be stationed on the sighting tower or catwalk of the dynamite drill barge.

In most cases this observer began conducting a surveillance approximately 30 minutes prior to a blast. However, when the number of charges was reduced, and the blast sequence was accelerated, the observer remained on duty continuously. Also, when animals were known to be in the area, additional observers were assigned to watch for manatees on the catwalk. When one of the observers sighted a manatee, the blasting crew chief was immediately contacted and the sequential plans for detonation were delayed. Not until the animal was well away from the blast zone was the okay given to blast. Sometimes when an animal was sighted near the danger zone but disappeared, an additional ten minutes were added to the blasting detonation sequence.

> Provision 8: An observer in a boat will make a systematic survey of the danger zone prior to blasting.

A 13 foot Boston Whaler Boat equipped with a 15 hp engine and a special aluminum protection prop guard was used to make a systematic coverage of the danger zone and the area neighboring the danger zone 20 minutes prior to a blast. Sometimes when animals were in the area, the observer in the boat would make surveys continuously. When an animal was observed, the boat operator immediately changed from a green “All Clear” T-shirt to a red “Danger” T-shirt. This allowed the blasting officer to know that there was a manatee in the area and immediately to halt the blasting sequence. Once the blasting sequence was stopped, members of the dynamite crew would climb to the top of the catwalk and assume observation positions. In most cases, the boat followed the animal until it was well away from the danger zone. Sometimes the distance would be 1000 meters or more. In no cases were animals chased or herded out of the area by the boat.

> Provision 9: An electronic color enhanced fathometer will be utilized to monitor underwater manatee movement.

After an extensive testing program was conducted over a six-week period during the fall of 1982, it was determined that a color enhanced fathometer could be used as a reliable manatee underwater detection device (Fletemeyer 1982, 1983). A color-enhanced fathometer (Model: Honda Si-Tex) was successfully used after the initial testing period for manatee detection during the winter seasons of 1982-83 and 1983-84 during a mechanical dredging project in the Port Everglades area (Fletemeyer 1983). The same equipment was used during the dynamiting project.

The fathometer was stationed on the southwest end of the drill barge and a specially designed double transducer system was submerged at a maximum depth of 19 feet below the surface. Because of potential damage to the transducers during blasting, they were removed from the water five minutes prior to each blast. Further, the fathometer was shut off prior to each blast because of the possible danger of prematurely setting off the blast by the electronic signal transmitted from the equipment.

RESULTS

During the period between 4 April and 8 May when this program was in operation, a total of 58 manatees sightings were made on 28 separate occasions were made. Three manatee observations were made using the Si-Tex color-enhanced fathometer, while the remaining number were visual observations made by either the boat observer or observers stationed on the drill barge. A total of 22 observations were made while the blasting was being conducted on the west side of the Intracoastal Waterway, while the remaining 32 observations were made on the east side. It is important to note that the observations do not necessarily reflect major manatee use areas.

These observations necessitated shutting down the blasting operation for a total of 14 times and for a total of 222 minutes (x = 15 minutes and 12 seconds). On April 19, 1984, because of the number of manatees observed near the dynamite drill barge, the operation was shut down prematurely and was not resumed until the next day.

PRESSURE FROM UNDERWATER BLASTING AND SAFE DISTANCES (1983)

Blasting underwater can produce pressure waves that can kill mammals and fish. The question is commonly asked as to what are distances where mortality will occur and at what distance from a blast can one expect fish kill? This section will address this problem.

MORTALITY IN MAMMALS

To protect mammals such as manatees, turtles, dolphins, etc. the following relationship had been suggested which originates from the Navy Diver Formula. The Navy Diver Formula is designed for unconfined charges. Research results from reports by Hempen and others indicate that this formula is very conservative. The research reports are in included in the appendices.

Caution zone radius = $260\ (\text{lbs/delay})^{1/3}$

Safe zone radius = $520\ (\text{lbs/delay})^{1/3}$

The caution zone is the radius from the blast where mortality will not occur, we plan to blast when all mammals are outside the safe zone radius, however, if a mammal is between the safe and caution zone, the blast would still be fired. If the mammal was at a distance less than the caution zone radius, the blast would be delayed until it was at a distance great than the caution zone radius. Note: This formula was developed from actual measured data at Port Everglades. More recent, data that will be discussed later in this report, from a study in 2003, at KVK project in New York District, with confined blasts, show these equation to be conservative.

EXAMPLES

An underwater blast is loaded with 64 lbs of explosive per delay. Calculate the caution zone radius.

Caution zone radius = $260\ (\text{lbs/delay})^{1/3}$

Caution zone radius = $260\ (64)^{1/3}$ = 1040 feet

An underwater blast is loaded with 64 lbs of explosive per delay. Calculate the safe zone radius.

Safe zone radius = $520\ (\text{lbs/delay})^{1/3}$

Safe zone radius = $520\ (64)^{1/3}$ = 2080 feet

12. ENVIRONMENTAL PROTECTION DATA (2001)

New data obtained from Port Everglades indicate that the Navy Diver Formula is extremely conservative for predicting safe distances from charges which are placed in boreholes. A new equation is proposed by Konya which better agrees with actual measurements of pressures generated in water from underwater blasts with explosives in boreholes. The general equation for predicting the distance at which the shock pressure in water is 50 psi is:

Safe zone = $132\ (\text{lbs/delay})^{1/3}$
= $132\ (64)^{1/3}$ = 528 feet

Caution zone = $56\ (\text{lbs/delay})^{1/3}$
= $56\ (64)^{1/3}$ = 224

The pressure from underwater blasts where explosives are in boreholes can be calculated from the relationship given below:

$$P = K(W^{1/3}/D)^{a}$$

Where:

P	=	psi
K	=	site constant
W	=	lbs/delay
D	=	distance in feet
a	=	site constant

Site specific propagation equations can be obtained if measurements are taken during the test blast program. Test data obtained from underwater blasting with explosives in boreholes at Port Everglades in 1983 produced a "K" constant of 1673 and an "a" constant of 0.87.

The site specific propagation equation is therefore:

$$PSI = 1673(W^{1/3}/D)^{0.87}$$

These constants give a 95% confidence level. Most of the data from which these constants were obtained were from single hole tests. Large blasts with multiple boreholes and delays could produce different values because of blasting cap tolerance in firing times.

13. REPORT NAVSWC MP 91-220 (1991)

Report NAVSWC MP 91-220 from the Navy is a compilation of data and research from open water blasts and the safe range in feet from theses open water charges. The reference is "Young, G. A., Concise Methods for Predicting The Effects of Underwater Explosions on Marine Life, **NAVSWC MP 91-220**, Naval Surface Weapons Center, Silver Spring".

The graphs and equations shown in this section are from MP91-220 and are very conservative because they were derived for open water explosions and not explosives placed in stemmed blastholes in rock.

The tables and figures below show results of Navy research and the vulnerability of mammals, fish and other species to shock effects from explosions in water. The tests and research were conducted with charges surrounded in water. The charges were not buried placed in blastholes and did not have the blastholes stemmed.

TABLE 1. VULNERABILITY CATEGORIES

CATEGORY I NON-SWIMBLADDER MARINE LIFE

Flounder

Shrimp

Lobster

Oysters

Crabs

Comments: Highly resistant to explosions. Predictions are based on experimental data. Injury mechanisms vary with species, but resistance is probably due to the absence of air cavities. Estimated range of vulnerability based on 90 percent probability of survival.

CATEGORY II FISH WITH SWIMBLADDERS

Comments: Small fish are more vulnerable than large fish. Fish near the surface are more vulnerable than deep fish. Prediction models are based on experimental data and an injury mechanism related to the response of swimbladder gas to the direct and reflected shock waves. Estimated range of vulnerability based on 90 percent probability of survival at a relatively shallow depth.

CATEGORY III SEA MAMMALS AND SEA TURTLES

Comments: Small sea mammals are more vulnerable than large. Estimates of effects are based on experiments with land mammals. Injury is related to the response of air cavities, such as the lungs and bubbles in the intestines, to the shock wave. Estimated mammal safe range is based on absence of injury. Estimated safe range for sea turtles is based on Gulf of Mexico oil platform criteria established by the National Marine Fisheries Service. As a satisfactory biological-response theory has not been developed for sea turtles, cube-root scaling is used.

CATEGORY IV SWIMMERS

Comments: Safe ranges are determined by limited experimental data and a prediction model based on response of lungs and bubbles in the intestines to shock waves. Hazard to swimmers increases with water and swimmer depth. As the safe range for swimmers exceeds that for all forms of marine life, this range is used for aircraft surveillance of a test site.

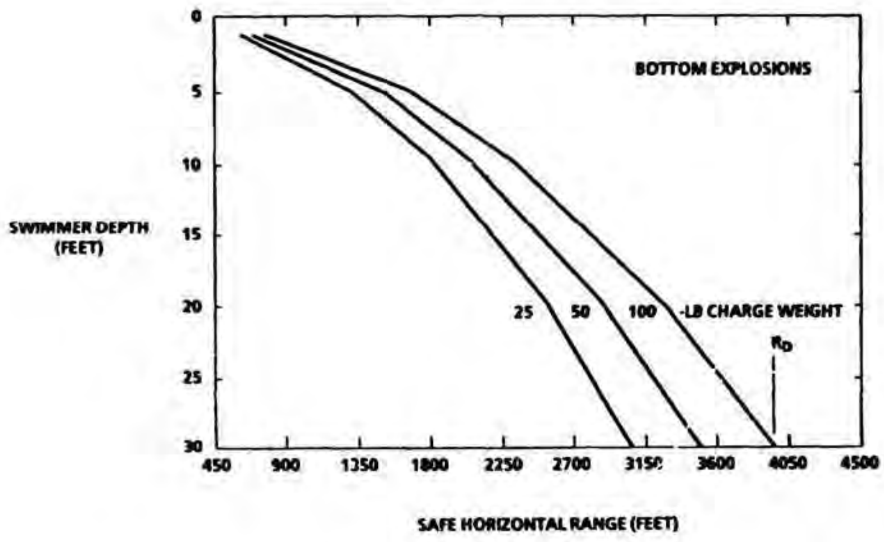


FIGURE 7. CONTOURS FOR SAFE RANGES FOR SWIMMERS IN SHALLOW WATER

NAVSWC MP 91-220

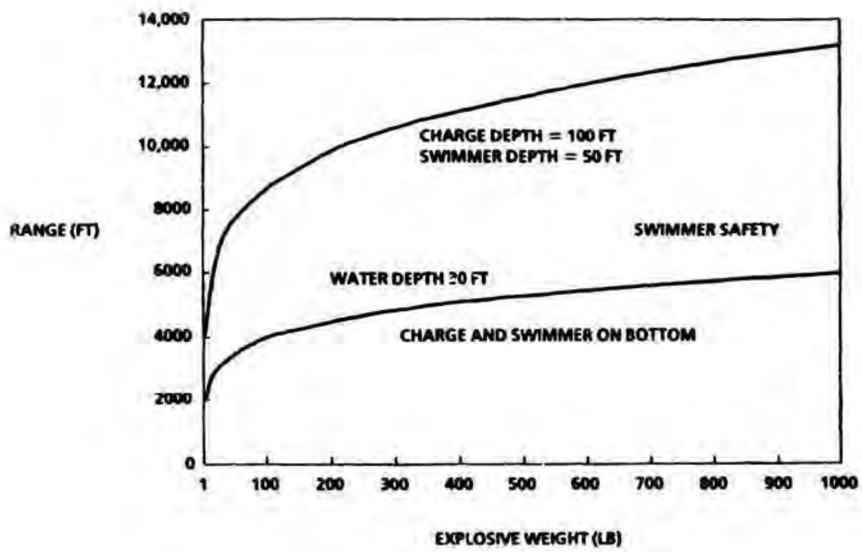


FIGURE 6. CATEGORY IV: SWIMMERS

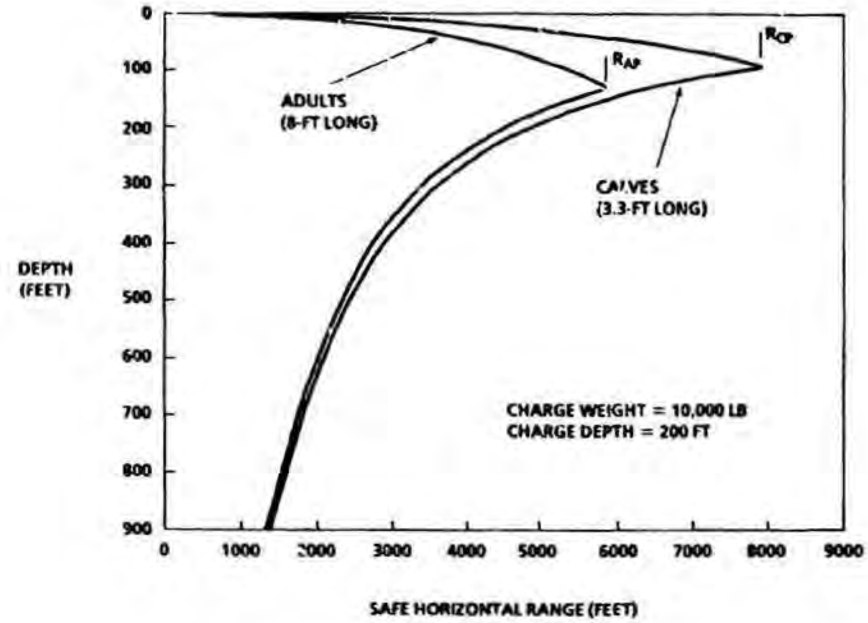


FIGURE 5. CONTOURS FOR SAFE RANGES FOR PORPOISES

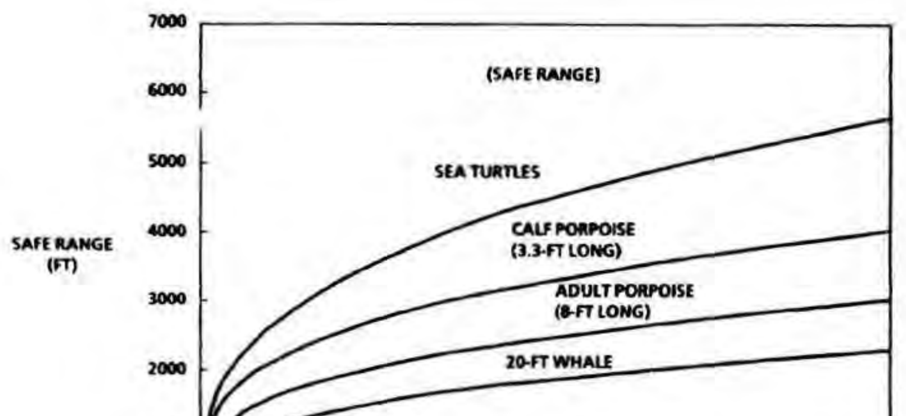


FIGURE 4. CATEGORY III: SEA MAMMALS AND SEA TURTLES

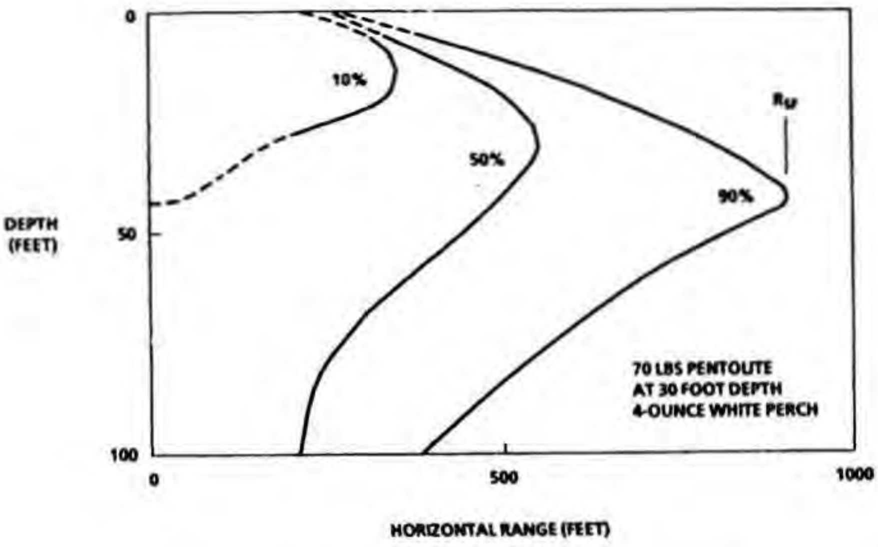


FIGURE 3 CONTOURS FOR SURVIVABILITY OF SWIMBLADDER FISH

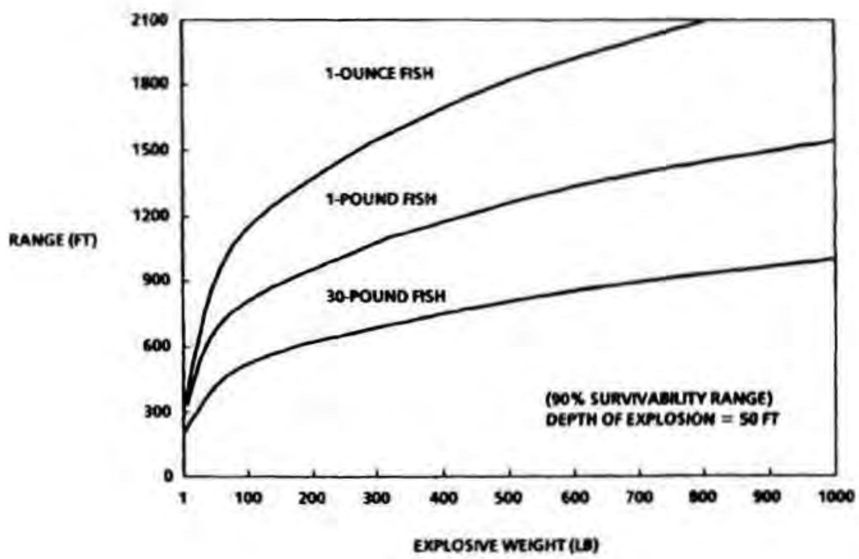


FIGURE 2 CATEGORY II: FISH WITH SWIMBLADDERS

NAVSWC MP 91-220

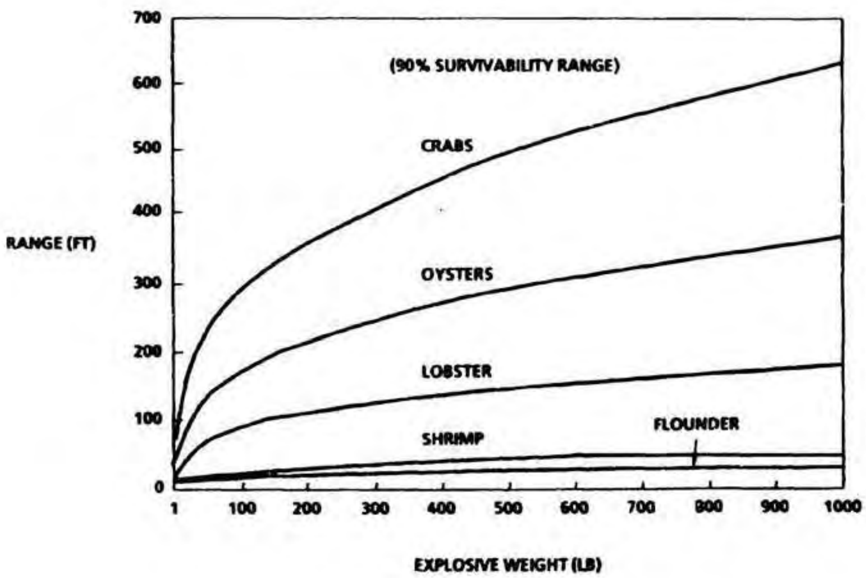


FIGURE 1. CATEGORY I. NON-SWIMBLADDER MARINE LIFE

NAVSWC MP 91-220

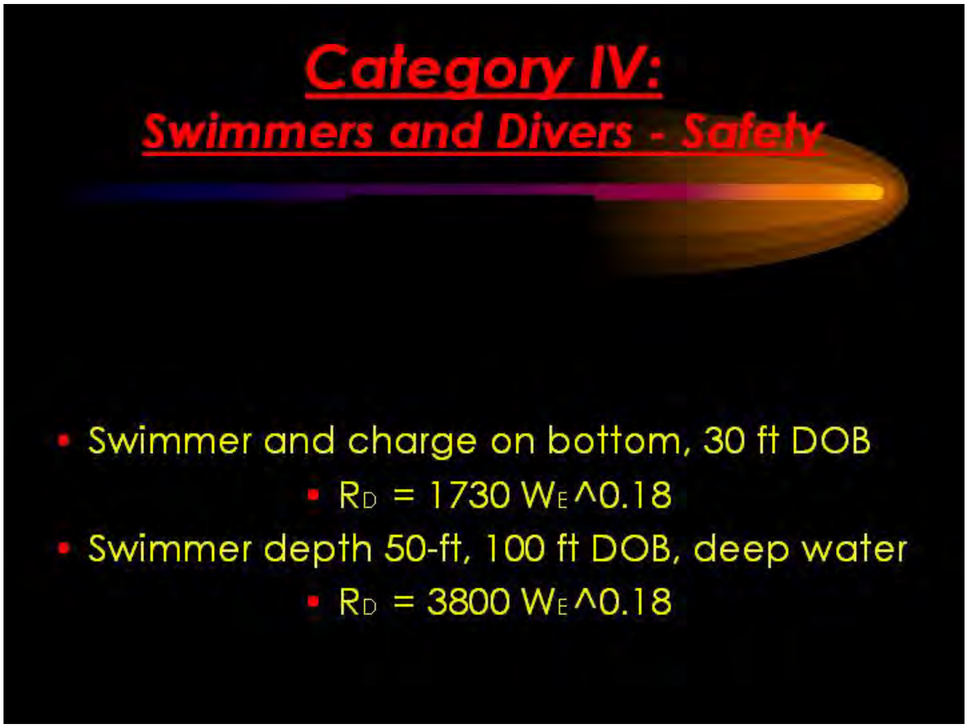
Category I:

Non-swim Bladder Marine Life
90 % Survival

Flounder	$R_{FL} = 3.38\, W_E\wedge 1/3$
Shrimp	$R_S = 5.39\, W_E\wedge 1/3$
Lobster	$R_L = 18.5\, W_E\wedge 1/3$
Oyster	$R_O = 37.4\, W_E\wedge 1/3$
Crab	$R_C = 63.4\, W_E\wedge 1/3$

Category III:
Sea mammals and Sea Turtles

- $R_{CP} = 578\, W_E\wedge 0.28$
  Calf Porpoise (@ 200ft DOB)
- $R_{AP} = 434\, W_E\wedge 0.28$
  Adult porpoise(@ 200ft DOB)
- $R_W = 327\, W_E\wedge 0.28$
  Whale (@ 200ft DOB)
- $R_T = 560\, W_E\wedge 1/3$
  Sea Turtle



14. KILL VAN KULL-NEWARK BAY CHANNELS PHASE II DEEPENING PROJECT, FINAL ENVIRONMENTAL ASSESSMENT DECEMBER 1997

A survey of fish distribution was conducted in Newark Bay from May 1987 - April 1988 to generate a baseline of data for fish distributions prior to Phase I deepening of the federal navigation channel through the area (Will and Houston 1992). Results were similar to those reported in the 1984 - 1985 study. The monthly samples indicated that fish were most abundant in the deeper waters of the navigation channel. The study concluded that the area supports large populations of many species of fish, including Atlantic tomcod and winter flounder.

From May 1993 to April 1994, the NMFS (1995) performed a biological and hydrographic survey of Newark Bay. A total of 56 species representing 37 families of fish and megainvertebrates were identified. Forty-three species of fish were collected in the ten Newark Bay channel stations compared to 23 species collected on the shoals. Overall, the ten dominant species, in decreasing order of abundance, were striped bass; Atlantic tomcod; male blue crabs, *Callinectes sapidus*; white perch, *Morone americana*; female blue crab; weakfish; winter flounder; spotted hake, *Urophycis regius*; rainbow smelt, *Osmerus mordax*; and grubby, *Myoxocephalus aenaeus*. These species dominated catches throughout the study accounting for greater than 94 percent and 92 percent of the total number and weight, respectively, of all species collected. The five dominant fish were most abundant during the following months: striped bass - November, February, and March; Atlantic tomcod - June, July, and August; white perch - November, February, and March; weakfish - August, September, and October; and winter flounder - August, November, and December. There was a distinct difference in the seasonal occurrence of fish between the channel and shoal stations. Fish were abundant in every month at the channel stations, while they were nearly absent from the shoals from November - April. Striped bass and white perch were particularly abundant at the channel stations during the winter months.

Shellfish collected during the NMFS (1995) study included, in order of abundance: blue crab, rock crab (*Cancer irroratus*), lady crab (*Ovalipes ocellatus*), spider crab (*Libinia emarginata*), horseshoe crab (*Limulus polyphemus*), American oyster (*Crassostrea virginica*), and soft-shelled clam. Bottom trawls in the channel produced more large invertebrates than shoal sampling. Blue crabs were collected in abundance only at the channel stations, accounting for 98.6 percent of the total number of invertebrates collected. The studies conducted for the SEIS (USACE 1986) did not note the importance of the channel habitat for blue crabs. These recent data indicate the deep channels are an important habitat for overwintering male blue crabs which burrow in the sediment during the late fall and winter in the north.

For the NBCDF DEIS (USACE 1997), the District conducted trawl sampling in shoal areas in Newark Bay and at a channel station near the Bayonne Bridge in the KVK and Goethals Bridge in the Arthur Kill from April 1995 to March 1996. Twenty-seven species of fish were collected in 1995 in the combined shoal and deepwater stations. Four species - grubby, scup, spot, and cunner were only collected in the channel station. Similar to the NMFS (1995) study, it was reported that shoal areas in Newark Bay are used by fish from late spring through fall, but fish are nearly absent from the shoals during winter. The 1995 - 1996 study did not find a difference in species representation or abundance among the four Newark Bay shoal stations sampled over a one-year period. The deeper navigation channels, on the other hand, were used throughout the year. During winter, fish abundance was high in channel areas and the fish community was dominated by few species, particularly striped bass and white perch. Four species, striped bass, winter flounder, summer flounder, and bay anchovy occurred in samples collected each month. Blue crabs were abundant at all shoal stations in Newark Bay. Their seasonal occurrence on the shoals was limited to April through October.

Length frequency distribution of the NBCDF samples (USACE 1997) indicated a broad range of striped bass occur in Newark Bay, encompassing age classes ranging from yearlings through the second year age class. There was an occurrence of a few individuals in the 10-40 mm range suggesting striped bass may have spawned in the Newark Bay vicinity.

In summary, the results of the recent studies agree with the results contained in the SEIS (USACE 1986) even though sampling equipment, methods, and sample designs varied among the studies.

Newark Bay and KVK contain a diverse fish community dominated by the abundance of a relatively small number of species. The dominant species - striped bass, winter flounder, bay anchovy, and Atlantic tomcod - were abundant or common in each study. The presence of large numbers of the smaller individuals of the dominant species shows that Newark Bay is an important nursery area for some species. A number of species occur commonly, but on an annual basis are generally present in smaller numbers or were present only for short periods of time. Blue crabs were abundant in the trawl samples in the NMFS (1995) study. They occurred on the shoals from April through October but not during the remainder of the year. They were present in the channel during the winter months, but their relative abundance during this time period may not have been well represented because they burrow into the sediment.

15. BLAST MONITORING PROGRAM FOR THE KILL VAN KULL DEEPENING PROJECT (2004)

DETONATION –SHOCK WAVE STUDY

The following sections were excerpted from sections of the report by the U.S. Army Corps of Engineers entitled "Blast Monitoring Program for the Kill Van Kull Deepening Project", July, 2004. There was minor editing of these sections to make the text properly flow from section to section. The entire report is given in the Appendix 1. The footnotes given in these sections can be found in the full report given in the Appendix 1.

For detonations in rock such as the KVK channel deepening project, the most important factors in accomplishing the work of fracturing and displacing rock in close proximity (3-10 diameters of the explosives volume) to the explosives material are thermal and high pressure detonation effects (Keevin and Hempen 1997). However, these effects have negligible impacts on aquatic organisms. Beyond this point in the far-field area, the primary source of damage to aquatic organisms is the shock wave.

The nature of the shock created by use of underwater explosives and physical factors that can affect fish survival is the composite result of multiple pressure wave components including the direct wave, air-water surface-reflected wave, bottom-reflected wave, and bottom-transmitted wave (McPherson 1991). The location of the explosive (e.g., mid-water, placement in bedrock) and method of detonation (e.g., single charge, multiple charges with delays) will affect these component waves that are the predominant factors that influence the character of the composite shock wave (Figure 3.2.1). The direct shock wave results in the peak shock pressure or compression and the reflected wave at the air-water surface produces negative pressure or expansion. For confined underwater explosives, these are the primary wave components responsible for injury to aquatic organisms (Wright and Hopky 1998; Keevin and Hempen 1997; Linton et al. 1985; Wiley et al. 1981)

One feature of blasting in aquatic environments is the "cavitation hat," related to the reflected wave in proximity to the air-water surface. The negative reflected wave generated by the deflection of the water surface toward the air results in a shallow disc of negative pressure centered over the explosive. There is high potential for overextension of air filled organs in aquatic biota due to the negative pressure associated with the cavitation hat.

The direct or primary shock wave (P-wave) in the far-field area is an expanding compression wave, marked by a rapid, nearly instantaneous increase to peak pressure (*Pm*) as it passes a given point at distance from the explosion followed by an exponential decline in pressure (Figure 3.2.1) to ambient hydrostatic pressure. The surface-reflected wave trails the direct wave and is characterized by a rapid decrease in pressure to below ambient followed by an exponential increase to ambient hydrostatic pressure. The resultant effect experienced by an aquatic organism in the path of this wave is a rapid sequence of compression and expansion (oscillation) over a period of microseconds depending on the distance from the detonation.

Three characteristics of the composite pressure wave generated from a detonation have been used to assess the impact of blasting on aquatic biota and predict safe ranges from detonation sites: *Pm*, impulse (*I*), and energy flux (*Ef*). *Pm* is a function of the weight (*W* in kg) of the explosive and the distance (*r* in meters) from the explosive:

$$\mathbf{Pm = 53.1 \times Rs^{-1.13}}$$

where *Rs* is defined as the scaled range,

$$\mathbf{Rs = r / W^{1/3}}$$

The equation to calculate *Rs* provides a means to scale the effects of blasting for different weights of explosive at a selected distance from the detonation (Linton et al. 1985). That is, *Pm* is proportional to the cube root of the weight of the explosive (*W*).

Impulse is a measure of the strength or momentum of the pressure wave as it passes a surface. The impulse is a function of the pressure (psi) and the time over which the pressure is produced (Linton et al.1985). It is calculated as the integral of the area under the pressure-time curve. Depending on their purpose, various authors have included either or both the positive and negative portions of the pressure-time curve in this calculation (Keevin and Hempen 1997). The severity of injury to fish is generally reported to be proportional to the magnitude of the impulse produced by the explosive (Linton et al.1985).

Energy flux density is a measure of the intensity of the shock wave or the change in energy across a surface in the path of the shock wave. It is measured in units of energy per unit area (e.g., joules/m2). The integral of *Ef* can be approximated in terms of *W* and *Rs* (Keevin and Hempen 1997). The shock wave energy is also affected by the detonation velocity of the selected explosive; higher velocity explosives generate greater energy. For example, water gel explosives as used for the KVK project generate less shock energy than dynamite.

The KVK blasting protocol has attempted to optimize production and reduce the environmental effects as defined by Keevin and Hempen (1997). Optimized blasting (Keevin and Hempen 1997) is accomplished by:

- Reducing the weight of explosive by accounting for the characteristics of the media blasting pattern, and the properties of the blasting material
- Use of water gel explosives
- Increasing the number of delays to progressively displace material
- Stemming boreholes to prevent pre-mature venting of explosive gases and dampen the pressure shock wave.

Blast Impacts on Aquatic Organisms

The primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, in particular the swimbladder (Wright and Hopky 1998; Keevin and Hempem 1997). The gas-filled swimbladder is a structure possessed by many pelagic fish that plays a role in buoyancy. Demersal species, such as flounder, typically do not have swimbladders and are frequently less susceptible to blast impacts. Less information is available, but it is generally reported that there is minimal injury and mortality from blasting to mollusks, shellfish, and crustaceans which do not have gas-filled organs similar to the swimbladder in fish (Wright and Hopky 1998). Although the structure of the swimbladder and the mechanism for adjusting gas volume vary among species, generally the process for release of gas from the swimbladder is too slow to compensate for the rapid fluctuations in hydrostatic pressure associated with the pressure shock wave. The primary cause of damage in finfish exposed to a pressure shock wave appears to be the outward rupture of the swimbladder as a result of the expansive effect of the negative hydrostatic pressure associated with the reflected air-water surface wave. While the organ may tolerate the compressive portion of the shock wave, the rapid drop to negative hydrostatic gage pressure and expansion of the gas that cannot otherwise be released, causes the rupture of the organ (see photo, below). Vibration, expansion, and rupture of the swimbladder can also cause secondary damage and hemorrhage due to impact with other internal organs in close proximity to the swimbladder.

Other organs typically exhibiting damage include the kidney, liver, spleen, and sinus venous. Extensive tearing of tissue has been observed in species where the swimbladder is closely attached to the visceral cavity. Close attachment to the dorsal cavity wall was typically associated with extensive damage to the kidney. Species with thick-walled swimbladders and cylindrical body shape (e.g., oyster toad fish and catfish) appear to be more resistant to pressure waves than species with laterally compressed bodies such as herring and menhaden (Linton et al. 1985). Smaller individuals of a species are generally more sensitive than larger fish. Early larvae do not have swimbladders and are more resistant than older larvae after development of the swimbladder. The extent of injury and mortality decreases with distance from the detonation as the magnitude of the pressure drop declines due to dissipation of the blast impulse (*I*) and energy flux density (*Ef*) with distance. In a review of a number of studies of primarily open water blasting, Keevin and Hempen (1997) concluded that *I* was the best predictor of potential damage for shallow depths (less than 3 m), while *Ef* was the best predictor for deeper conditions. The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality, although water depth, substrate, depth of the fish, and size and species of fish are also important (Keevin and Hempen 1997; Wiley et al. 1981; Teleki and Chamberlain 1978). The shape of the lethal zone is dependent on the depth of the detonation. In shallow water, the horizontal extent is greater than in deep water. However, for buried explosives, the lethal zone is conical with the narrow portion of the lethal zone near the bottom expanding horizontally toward the water surface (Linton et al. 1985).

Several authors have developed empirical models to integrate these factors in order to predict impacts to aquatic organisms; however, most of these are based on open water detonations and thus, overestimate the lethal range and impact to fish compared to blasting with explosives buried in the substrate as is the case for the Kill Van Kull project. Keevin and Hempen (1997) reviewed several of these models. A set of computer models was developed by Coastline Environmental Services (1986) that can provide rough approximations of the potential lethal radius for open water and buried borehole blasts based on *I* (IBLAST) for shallow water and *Ef* (EBLAST) for deep water sites. The Canada Department of Fisheries and Oceans evaluated *Pm*, *I*, and *Ef* as predictive parameters for establishing guidelines for protection of fish and marine mammals during use of explosives in Canadian waters (Wright 1982) and found an impulse-based model to be the best predictor of lethal and safe ranges. Wright found that overpressure greater than 100 kilo Pascals (kPa) (14.5 psi) generally caused internal organ damage in finfish. This 100 kPa threshold has been used a guideline to limit blasting impacts in Canadian waters (Wright and Hopky 1998). However, based on reviews of several studies, Wright (1982) reported that *Pm* is affected by an array of factors, including size and species of fish, orientation of fish relative to the direction of the pressure wave, target depth, detonation depth, water depth, bottom type, and explosive type and quantity and thus, was a poor predictor of lethal range. Predictive equations (MacLennan 1977) for lethal range based on *Ef* were inconsistent in their ability to predict lethal ranges under different test conditions (Hill 1978; Roguski and Nagata 1970; Hubbs et al. 1960; Tyler 1960). Field tests (Yelverton et al. 1975) indicated that the lethal impulse values were relatively consistent for various test conditions, but peak lethal pressures varied widely. In a series of tests with bluegill and carp, Wright reported that while peak pressure remained constant with depth at test locations, the impulse and mortality increased with depth. Wright presents a procedure (based on Hill 1978) to calculate the lethal range based on scaled impulse (*Isc*) (calculated from an impulse value detonation depth). Scaled impulse is calculated as;

$$\mathbf{Isc = I / W^{1/3}}$$

and compared to *Rs* using a series of curves that relate *W*, the depth of the charge (*Dc*), and depth of the fish (*Df*):

$$\mathbf{A = (Df \times Dc) / W^{2/3}}$$

The lethal range (*Rm*) is calculated from *Rs* selected based on the ratio, *A* and the calculated *Isc*:

$$\mathbf{Rm = Rsc \times W^{1/3}}$$

Wright concludes that the method will underestimate *Rm* in shallow water if the water depth is less than 5 times the detonation or fish depth or for rocky bottoms. On the other hand, Wright's procedure is based on field data secured from open water blasts and will overestimate *Rm* relative to situations where the explosive is placed in stemmed boreholes. In reviewing Wright (1982) and Hill (1978), Keevin and Hempen (1997) indicate that a more precise model would do little to improve the accuracy of the predicted lethal zone, considering the number of conditions that affect mortality, but are difficult to quantify. Examples of information that can generally only be assumed at the time of a blast include: size distribution of fish, depth and horizontal distribution of fish, and fish community structure. Keevin and Hempen indicate that a conservative estimate of potential mortality is provided by the using the model to assess "worst case" potential impact. Young (1991) presented a model to estimate the range of vulnerability using 90 percent probability of survival as the threshold criteria. This model was generated for shallow water conditions and open water blasts. Because the model is based on a limited range of conditions, Young characterized it as useful for preliminary planning purposes:

$$\mathbf{Rsafe = 95 \times Wf^{-0.13} W^{0.28} Dw^{0.22}}$$

Where:

Rsafe = Safe range (ft)
W = Weight of explosive (lb)
Wf = Weight of fish (lb)
Dw = Depth of detonation (ft).

Wiley etal. (1981) developed a dynamic model to simulate the effect of the passage of a pressure shock wave on the oscillatory vibration of a generic swimbladder (Figure 3.3.1); modeled estimates of swimbladder motion (oscillation parameter *Z*) were correlated with severity of observed injury to fish in caged studies with open water blasts. They present a method for calculation of the probable distribution of mortality as a function of horizontal range and depth. The authors found good agreement between their oscillation damage parameter and the impulse damage parameter developed by Yelverton et al. (1975). It is suggested that this similarity occurs because the oscillatory motion described by their model is a result of the impulse pressure loading on the swimbladder air volume. The model and relationships between characteristics of the pressure wave and severity of injury observed by Wiley et al. were consistent only for detonations in shallow water. Using an average relationship between fish length and swimbladder radius for striped bass, Wiley et al. calculated estimated kill zones (90, 50, and 10 percent) for striped bass shown on Figure 3.3.2. The authors also presented estimates of variation in mortality as a function of both depth and fish size (Figure 3.3.3). Field tests were performed where water depth was 46 m to minimize the affects of reflected bottom pressure waves; 14 of 15 blasts monitored were detonated at a depth less than approximately 12 m. The testing program looked at a number of species that may be seasonally abundant in the NewYork/New Jersey Harbor complex including white perch (*Morone Americana*), spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*), blueback herring (*Alosa aestivalis*), hogchoker (*Trinectes maculates*), toadfish (*Opsanus tau*), and killifish (*Fundulus majalis*). Hogchokers, a species with no swimbladder, were reported to sustain no serious injury. Wiley et al. reported that the damaged swimbladder of some species, such as white perch and spot, healed in as little as 10 days under laboratory conditions, but that the organ was less effective in controlling internal hydrostatic pressure and buoyancy.

The U.S. Army Corps of Engineers – Wilmington District (2000) examined the results of test blasting in Wilmington Harbor/Cape Fear River used to evaluate the model predicted impact zone and the effectiveness of impact reduction using an air bubble screen. This report found that field tests with caged fish demonstrated that the impact modeling conducted for the Environmental Impact Statement on this project significantly <u>overestimated</u> the horizontal extent of fish mortality. The model-predicted impact area (USACE 1996a, 1996b), defined as that area in which 1 percent or more of the fish would die without an air curtain, extended to 656 ft from the blast (34.5 acres).

<u>In field test, no significant mortality occurred beyond 140 ft (2.1 acres within 140 ft) with or without the air curtain.</u>
<u>The U.S. Army Corps of Engineers – Wilmington District (2000) suggested that the reason for the significant overestimate by the model was that the Environmental Impact Statement model underestimated the reduction in blast effects compared to open water by confining the explosive in rock.</u>

The test blasts consisted of 32 to 33 holes with 52 to 62 pounds of explosive per hole with 25 microsecond delays; water depths were 30 to 38 feet. **<u>The Waterways Experiment Station found that the effect of a rock blast is 0.014 of a blast in open water; this translates to an equivalence of a 52 to 62 pound blast in rock to a 0.73 to 0.87 pound blast in open water.</u>**

This data can be used to calibrate the older equations that were developed for blasts in open water.

The reported average *Pm* and average peak *I* from the test rock blasting at the 140-ft radius were 75.6 psi and 18.4 psi-msec, respectively; it was reported that these values were similar to impact threshold values estimated by Yelverton et al. (1975). It was suggested that the ineffectiveness of the air curtain was a result of the strong tidal currents in the Cape Fear River that disrupted the air curtain and the establishment of an effective air barrier

16. WATER-BORNE PRESSURES FROM CONFINED BLASTS, KVK (2003)

The purpose of the study was to record water-borne blast pressures from confined blasts conducted in the Kill Van Kull and relate them to impacts to resident fishery resources. The blasting was part of the ongoing Kill Van Kull (KVK) Deepening Project. The blasting was confined within the rock floor of the KVK to remove rock for channel deepening. The United States Army Corps of Engineers - New York District funded the study in an effort to record data from actual confined blasts. These data were then compared to data recorded from open-water blasts, which are unconfined and produce higher peak pressures in the water column. The pressure data was recorded to measure the various typical pressures associated with impacts to aquatic and marine organisms. The blast monitoring was conducted during the last two weeks of October 2003.
The formulas and computational methodologies used to develop the information contained in the following chapter are highly technical and have thus been included in an expanded version of this chapter included as Appendix 3.

Channel Deepening Blasting

The location of the blasting in October 2003 was near the Bayonne Bridge at Bergen Point. Acceptance areas A and B, east of the bridge, were the locations of the removal program. Figure 4.2.2 provides a typical section for channel depth and rock removal.

Types of Explosives and Initiation

The main blasting agent used in October 2003 by the Joint Venture was EL957C, a water gel explosive, manufactured by ETI Canada Ltd. The water gel is not cap sensitive. The water gel has a specific gravity of 1.30 and a detonation velocity of near 20,000 feet/second (fps). The blasting agent was packaged in 2.75-inch (in) diameter polythene sleeves, each weighing 4.23 pounds (lb). Typically charges ranged between 25 and 29 lb per shot hole, depending on the height of rock relative to the dredge depth of 53.5 feet (ft). Larger water gel weights were often used in one or more holes for each shot.

The initiation system was comprised of a Detaline dual path, precision delay, **non-electric** initiation cord and components. By using a non-electric initiating system the shot was safely initiated and connected without concern for radio silence. Radios can initiate electric systems. The system utilizes a fine extruded detonating cord with a PETN explosive core of 2.4 grains per ft.

The timing and delay sequence to the shot holes were achieved with "Detaslide Delays" detonators. The detonators were used in each booster and were connected via Detaline to"Detaline Surface Delays." The surface delays were connected to a dual trunk of Detaline. All the shot holes were drilled, loaded and connected to the dual trunk line. The shot was initiated using a "Noiseless Lead-in-Line." An instantaneous detonator was attached to a 500-ft length of hollow shock tube that contained explosive dust. The entire shot was initiated by a simple shot-shell primer, which was fired into the shock tube connected to the trunk line delay system to the individual shot holes.

Upon initiating the blast, each cord carries the detonation to its shot hole. In doing so, the cord itself sets up a "tubular" pressure front that forms around the cord along its entire length. How the pressure from the multitude of Detalines affected the recorded blast pressures or how the lines may impact fish (if separate from the confined blasts) is unknown at this time. It can only be assumed that these "other" pressures were incorporated into recorded values.

Shot Patterns Tested

The October 2003 work consisted of a second round of rock removal to assure that the planned channel grade was obtained. This action was conducted to remove high rock points remaining from the first round of shooting to achieve the proposed pay grade. A planned pattern deployment positioned the drilling barges using GPS surveying equipment. Rock above the pay grade was drilled and shot. When rock was not encountered on the pattern above the pay grade, there was no need to place any blasting agent. To prevent the escape of gas and resultant explosive force each blast hole is "stemmed" with gravel or similar materials after the explosives are placed and the Det-Cord is connected. The type and length of stemming are important measures for confinement. Confinement is an important aspect of reducing the pressure by restricting riffling into the water channel above the shot hole. Previous contact indicated that 5/8-inch to ¾-inch, crushed stone was used as stemming with a minimum stemming length in rock of 30 inches.

Timing and Charge Weight per Delay

The delay sequence was resolved by a predetermined evaluation plan and placed by the number of holes drilled in each range and the number of ranges for the particular shot. Thus the actual delay timing deployed was a process of both the plan and the actual holes that were found above the pay grade.

The charge weight per delay is an important element of the blast vibration and water-borne pressure waves. The maximum charge weight per delay is the parameter that will likely be the predictor of the maximum vibration in particle velocity and the maximum water pressure. The maximum charge weight per delay is the largest weight of blasting agents shot at a single delay interval of less than 9 milliseconds (ms), 0.009 second (s). The largest weight may be attributed to a single shot hole or several shot holes with the same delay timing. It so happens that the recorded shots were from single shot holes with maximum charge weights per delay in the 70 to 90 lb per delay range.

STUDY RESULTS

Actual maximum pressures were successfully recorded in the adverse (radio-wave) environmental conditions of this channel reach. The maximum, high-quality pressures are relatively small compared to the theoretical value of an equivalent charge weight, in open water.

The complex pressure waveform does not allow integration of the pressure record to determine impulse and energy flux density.

Study Limitations

There were some obstacles to overcome in coordination and capture of the blast pressure-wave monitoring. The primary difficulties were: weather conditions, coordination of a shot's exact timing, interference in the noisy radio-frequency environment, cable saturation/lowering of the dielectric capacity, and low blast pressure released into the water column. The team was operationally able to record shots from about 21 through 30 October 2003. Pre-triggering and interference problems prevented the first shot (2MB-008) from being captured, but relative to later shots the Shot 008 pressure values were likely below the triggering level to be recorded. Pressure waves have been recorded that are attributed to the blasting. The system was available to record blasting but did not trigger recording for several shots: 2MB-008 (22 Oct 03), 2MB-011 (22 Oct 03), and 2MB-020 (28 Oct 03). It has been judged that the system was functioning, but that the pressures were below the trigger levels to record pressure data. Low-threshold triggers are required because there is not a physical link to the blast initiation. Pressure waves were recorded for shots: 2MB-010 (22 Oct 03), 2MB-014 (23 Oct 03), 2MB-021 (29 Oct 03), and 2MB-022 (30 Oct 03). One attempt to record a small charge, open-water blast was unsuccessful due to unsuccessful communication of the timing and perhaps too great of a distance between the shot location and transducers. Another open-water shot could not be coordinated. For detailed description of limitations see Appendix 3.

DISCUSSION OF RESULTS

The maximum pressures of four shots were successfully recorded. Quality, maximum pressures are shown in bold in Table 4.2.5 (original report). The maximum pressures and their waveforms show very short duration peaks that may be related to destructive interference from a complex shot pattern. There is reasoning that having a uniform maximum charge weight per delay could reduce some of the maximum peaks, but this is a hypothesis. For several of the shots the maximum charge in one shot hole was several multiples of most other holes.

BLAST PRESSURES

The maximum pressures from the confined shooting are significantly lower than theoretical open water shot pressures. Radiation of the wave energy into rock reduces the available energy reaching the water column. The pressures entering the water column are well below those pressures that typically propagate away from open-water (unconfined by solid media that may radiate the energy away with less harm) charges relative to charge weight per delay. The maximum pressures recorded are related to the maximum charge weight per delay. This cannot be directly correlated due to the complexity of shot pattern and potentially to the confinement of the charge within the rock. The number of drill holes and the average charge weight per delay varied among shot patterns. Uniform charge weight per delay would likely have had less variable impact on stunning and killing fish. When there is a need for a drill hole with a large charge weight per delay relative to other array borings of average charge weight per delay, the position of the boring with the maximum charge weight per delay is important. At the outer perimeter the boring with the maximum charge weight per delay will extend the kill radius significantly in the direction away from the shot pattern's borings. The boring with the maximum

charge weight per delay will have a lower impact when it is positioned near the center of the shot pattern. The lowered impact is due to the kill radius of the worst impact drill hole needing to surpass the kill radii of the surrounding borings with smaller kill zones due to their average charge weights per delay. The maximum pressure clearly is unrelated to the total weight of blasting agents shot. Shot 014 had only 98 lb total explosive weight but had comparable maximum pressures to other shots with many multiples for the total charge weight. The shot pressures were relatively uniform, while the shots varied significantly in total charge weight.

BLASTING IMPACT: FISH MORTALITY

Hubbs and Rechnitzer (1952) determined that the lethal threshold peak pressure for a variety of marine fish species exposed to dynamite blasts varied from 40 psi (280 kilopaschals, kPa) to 70 psi (480 kPa). Keevin (1995) found no mortality or internal organ damage to bluegill exposed to a high explosive at pressures at or below 400 kPa (60 psi). Canadian guidelines for the use of explosives have established the conservative value of 100 kPa (15 psi) as the "theoretical lethal range" (i.e., the range, or distance, over which the overpressure exceeds 100 kPa or 15 psi).

Fish kill was likely very close to the placed charges. The actual limits of the kill radii cannot be determined without caged fish. Stunned and killed fish were recovered by handnet from the surface. Many fish noted at the water surface after a shot may have been only stunned and may have recovered except for immediate predation by gulls (see photos and tables in attached in the KVK report in Appendix 3.

The NY District had initially planned to trawl for dead and stunned fish after each recorded blast. Several issues arose which prevented those plans from being executed. First, safety guidelines prevent any craft from approaching the blast area for about 10 minutes *after* the blast due to a loss of buoyant force in the water caused by release of gas from the explosion. By the time the "all clear" is sounded, the currents in the KVK had most likely widely dispersed fish located below the surface. Second, the complexity and logistics of setting up each shot pattern and need for the contractor to make frequent changes in the blasting schedule made keeping a contracted boat and crew on standby infeasible. There are a number of physical attributes of the pressure waveform from the confined shots measured in this study that may suggest that mortality would be lower than indicated by the peak pressure measurements. The impulse of a pressure wave gives the best indication of potential organ damage and mortality (Keevin and Hempen 1997). The impulses from the KVK confined shots were unable to be assessed for the lowered amplitude pressures within the rapidly alternating noise field. The rapid oscillation from a high, brief overpressure and a moderate, but longer, underpressure associated with detonation of high explosives in the water column is most probably responsible for fish mortality. This oscillation in waveform is responsible for the rapid contraction and overextension of the swimbladder resulting in internal damage and mortality.

It has been suggested that the negative phase (relative to ambient) of the pressure wave is responsible for organ damage (particularly the swimbladder) and mortality (Keevin and Hempen 1997). This conclusion was reached by the observation of swimbladders that were burst outward. For example, postmortem observations of striped bass (*Morone saxatilis*) and trout (*Cynoscion regalis*) found "the edges of holes in the swim bladder were turned outward and that blood from broken vessels in the wall of the bladder had been blown into the abdominal cavity" (Anonymous 1948). During the current study, the abrupt compressing pressures, usually associated with the detonation of high explosives, were reduced in amplitude and negative pressures were not observable relative to the background noise.

The more conservative pressure of 40 psi from Hubbs and Rechnitzer (1952) was used as a basis of mortality, even though their range extends to 70 psi and Keevin (1995) found pressures below 60 psi did not impact small, fresh-water fish. This is also a conservative standpoint because the waveform of the tested citations were from open-water tests and not from similar confined shots that did not have clear extension phases for measurable impulse and energy measures. Mortality is presumed when fish are exposed to 40 psi, but not killed below 40 psi. There is some evidence, as stated in preceding paragraphs, that confined shots would not have mortality pressures as low as those open-water shots. The recorded data of Table 4.2.5 (in KVK report) clearly demonstrates that no fish would have been killed at the recorded distances; 480 to 660 feet (Table 4.2.2), from the KVK confined shots.

Theoretically, equivalent open-water shots would have killed fish beyond these distances. As the pressures required to trigger recording for Shot 020 did not exceed 34 psi, this recording distance, 250 feet, would not have been lethal. Cole's equation for the open-water pressures may be manipulated using the lethal pressure of 40 psi. The mortality radius for single, open-water shots, $MR_{OW,}$ is:

$$\mathbf{MR_{OW}\ (feet) = 260\ W_{OW}^{\ 1/3}}$$

Where:

W_{OW} = the maximum charge weight (in pounds) per delay of a single, open-water blast.

The data set of Table 4.2.5 for KVK confined, channel rock-removal blasting may be resolved to an equivalent form of Cole's equation. The assumption, which is conservative for mortality, is that the attenuation factor is similar for both explosive positions; the attenuation should be greater for rock. Insufficient information has been collected to resolve the rock attenuation exponent for attenuation. The maximum pressure, P_C, from a single confined charge for the KVK data is:

$$P_C\ (psi) = 5{,}600\ SD_C^{-1.13}$$

where:

SD_C = the confined scaled distance and $SD_C = d / (W_C^{\ 1/3})$,
d = is the distance from the single confined blast to the point of pressure value, P_C,
W_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

The mortality radius for confined shots from the KVK data may be resolved from the confined. pressure equation and using the lethal pressure of 40 psi. The mortality radius for single, confined shots, MRC, is:

$$MR_C\ (feet) = 80\ W_C^{\ 1/3}$$

where

W_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

Theoretical mortality radii are computed and listed in Table 4.4.1 (typo in original report lists table 4.2.6) The table lists (for the six shots where the transducer array was in place) the number of drill holes shot and the maximum charge weight per delay of each shot. The table provides the leading and lagging distances for each shot from the boring with the maximum charge weight per delay to the transducers. For three shots the boring with the maximum charge weight per delay was the closest boring to the transducer array. For Shots 014, 021 and 022 the typical 25-lb charged boring was the closest boring to the transducer array. Both MRC and MROW, which are theoretically determined, are given in Table 4.4.1. MRC and MROW for the typical 25-pound charge in a boring are 230 and 760 feet, respectively. For most shots there was a field of borings all with 25-lb charges, except for one to three drill holes with a larger maximum charge weight per delay. The noted MRC may be more conservative, or larger, than the actual mortality radius, as noted above. MRC is less than one third the corresponding radius of equivalent single, open-water blasts. The complexity of the shot pattern and heterogeneity of the rock cause the actual pressures to have greater amplitudes than pressures from a single shot.

CONCLUSIONS FROM BLAST MONITORING

Pressure waves from the actual confined shots of the KVK rock removal program were recorded. The pressure waves and their maximum amplitudes were determined for four shots. The pressures from the confined shots were significantly lower than equivalent shots theorized as detonated in the water column. An equation was approximated to predict maximum pressures from the confined shooting of the KVK rock removal. Theoretical mortality relations were resolved for both confined and open water shooting. The confined mortality radii may overestimate the kill zones for fish, as there is insufficient data on fish kill at this location and other measures of impulse and energy, which could be used to corroborate the maximum pressure impacts, could not be attained. The mortality radii for the performed confined blasting are much smaller than equivalent open-water mortality radii.

MIAMI HARBOR PHASE II PROJECT

Hempen et al 2005, Jordan et al conducted research and presented a technical publication entitled "UNDERWATER BLAST PRESSURES FROM A CONFINEDED (sic) ROCK REMOVAL DURING THE MIAMI HARBOR DEEPENING PROJECT" at the Society Of Explosives Engineers Conference in 2007. The entire publication is given in the Appendices.

The conclusions from the project were excerpted from the publication and are given below.

The maximum pressures from the confined shooting were significantly lower than much smaller charges shot in open water. For Example, the kill radius of the 1-lb (0.45-kg) booster shot in open water, based on the results of Equation 2, was 260 ft (80 m). The kill radius would have only been 56 ft (17 m), as a conservative assessment, for a 1-lb charge that was confined by stemming within rock at Miami Harbor. The same charge may only have a kill radius of 22 ft (6.7 m) or smaller when confined within competent rock that was properly stemmed for confinement. The kill radii for the confined shots recorded at Miami Harbor of 17, 32, 67, and 134 lb/delay may have been calculated as 140, 180, 230 and 290 ft, respectively. Radiation of the wave energy into rock reduced the available energy reaching the water column. The pressures entering the water column were well below those pressures that typically propagate away from open-water (unconfined by solid media that may radiate the energy away with less harm) charges relative to charge weight per delay.

These study results corroborate previous laboratory studies and field studies that found reductions in peak pressure from confined shots. Nedwell and Thandavamoorthy (1992) compared the pressure time histories from the detonation of small explosive charges (1.8 g ICI Star detonator No. 8) in both free water and embedded in concrete blocks under laboratory conditions. They found that the peak pressure of the water-borne shock wave following the detonation of an explosive charge embedded in a borehole was about 6% (94% reduction) of that occurring for the same charge at the same distance, when it was freely suspended in water. Hempen et al. (2005) evaluated pressure reductions during channel deepening for the KVK. They compared pressures from four confined shots with computed open-water pressures and found that the confined pressures were only 19 to 41% (81 to 59% reductions) of openwater pressures. The mortality radius was 30% of the open-water shot and the mortality area of the confined shot would be only 9% of the mortality area for the open-water shot. Note that for the KVK, the largest calculated fish mortality was 350 ft (105 m) for a shot pattern containing 28 boreholes, with an 87 lb being the largest charge per delay shot. The mortality radius for moderately confined holes of Miami Harbor was 22% of the open-water shot and the mortality area of the confined shot would be only 5% of the mortality area for the open-water shot.

The maximum pressures recorded were related to the maximum charge weight per delay and clearly were unrelated to the total weight of blasting agents (e.g., sum of all the explosive weights in the bore holes detonated in a shot) that were detonated. The shot pressures were relatively uniform, while the shots varied significantly in total charge weight. Total charge weights for the blasting cap, 1-lb booster, and three pattern shots were: 1 cap, 1 lb, 136 lb, 408 lb and 408 lb. [Data for the blasting cap was recorded but is not reported within this paper to save space.] Maximum recorded pressures (without correcting to a common distance) in order of total charge weight were: 41 psi, 67 psi, 290 psi, 43 psi, and 90 psi. It is easy to note the largest pressure of 290 psi {2,000 kPa [136 lb (61.7 kg), total charge weight; 17 lb (7.7 kg), charge weight per delay]} was for the poorly confined hole of AP36. The range of total charge weights exceeds a multiple of 1,000, while the maximum pressures clearly do not correlate to total charge weight.

Parameters other than total charge weight control the maximum pressure and impulse. Hempen et al. (2005) found similar results for the KVK. KVK Shots 014 and 010 produced comparable peak pressures. Shot 014, had only two shot holes, with a maximum charge weight per delay of 72 lb {33 kg (total charge weight of 98 lb (44 kg)]}, while shot 010 had 25 shot holes, with a maximum charge weight per delay of 73 lb {33 kg [total charge weight over 1,500 lb (680 kg)]}. These results support the suggestion of Munday et al. (1986) that the use of delays effectively reduces each detonation to a series of small explosions. Resulting blast overpressure levels are directly related to the size of the charge in each delay, rather than the summation of charge weights detonated in all holes. The use of delays has been suggested as a potential mitigation measure to reduce pressure exposure to aquatic organisms (Keevin 1998). Protection of marine species at the Miami project is discussed in Appendix 4.

17. USACE SAFETY ZONE REQUIREMENTS, JACKSONVILLE DISTRICT (2012)

The US Army Corps of Engineers-Jacksonville District (Corps) has determined that the following federally protected species can occur in the Jacksonville Harbor Navigation Study area and may be affected by the proposed blasting: sea turtles, Florida manatee, northern right whale, bottlenose dolphin, shortnose sturgeon, and smalltooth sawfish. In accordance with the Endangered Species Act and the Marine Mammal Protection Act (MMPA), the study will be coordinated with the US Fish and Wildlife Service and National Marine Fisheries Service. The study will also be coordinated with the Florida Fish and Wildlife Conservation Commission.

The Corps proposes the following environmental restrictions in order to protect these species during blasting operations. As previously stated, these restrictions shall be coordinated with the appropriate agencies and are subject to change.

In light of the research conducted on underwater blasting in the last 12 years one can only say that these requirements are extremely conservative.

1. Work Stoppage Window: Blasting operations shall not occur from March 1 through November 30.

2. Blasting Operations: Danger, safety and monitoring radii would be based on the delay weights of an unconfined charge, however for this project; all charges would be confined in the rock.

Radii calculations:

The exclusion zone is defined as the Danger Zone plus 500 feet.

$$\text{Danger Zone radius} = 260\ (\text{lbs/delay})^{1/3}$$

$$\text{Safety Zone radius} = 520\ (\text{lbs/delay})^{1/3}$$

The watch zone will be three times the Danger Zone radius.

The following standard conditions will be incorporated into the project specifications to reduce the risk to protected species within the project area.

For each explosive charge placed, three zones will be calculated, denoted on monitoring reports and provided to protected species observers before each blast for incorporation in the watch plan for each planned detonation. These zones are:

Danger Zone: The radius in feet from the detonation beyond which no expected mortality or injury from an open water explosion is likely to occur. The danger zone (ft) = 260 X the cube root of the weight of the explosive charge in pounds (tetryl or TNT). Detonation will not occur if a marine mammal or reptile is known to be (or based on previous sightings, may be) within the circular area around the detonation site with the Danger Zone + 500 feet. This is referred to as the Exclusion Zone.

Safety Zone: The approximate distance in feet beyond which injury (Level A Harassment as defined by the MMPA) is unlikely from an open water explosion. The safety zone (ft) = 520 X cube root of the weight of the explosive charge in pounds (tetryl or TNT)

Watch Zone: Three times the radius of the Danger Zone to insure that animals entering or traveling close to the exclusion zone are spotted and appropriate actions can be implemented before or as the animal enters the exclusion zone (i.e. a delay in blasting activities).

3. The watch program shall begin at least one hour prior to the scheduled start of blasting to identify the possible presence of manatees, dolphins, marine turtles, or whales. The watch program shall continue until at least one half-hour after detonations are complete.

4. The watch program shall consist of a minimum of six Protected Species Observers. Each observer shall be equipped with a two-way radio that shall be dedicated exclusively to the watch. Extra radios should be available in case of failures. All of the observers shall be in close communication with the blasting subcontractor in order to halt the blast event if the need arises. If all observers do not have working radios and cannot contact the primary observer and the blasting subcontractor during the pre-blast watch, the blast shall be postponed until all observers are in radio contact. Observers will also be equipped with polarized sunglasses, binoculars, a red flag for backup visual communication, and a sighting log with a map to record sightings. All blasting events will be weather dependent. Climatic conditions must be suitable for optimal viewing conditions, determined by the observers. The Corps may also deploy boats equipped with passive sonar to assist with the monitoring.

5. The watch program shall include a continuous aerial survey to be conducted by aircraft, as approved by the FAA. The event shall be halted if an animal(s) is spotted within the Exclusion Zone (Danger Zone + 500 feet). An "all-clear" signal must be obtained from the aerial observer before detonation can occur. The blasting event shall be halted immediately upon request of any of the observers. If animals are sighted, the blast event shall not take place until the animal(s) moves out of the area under its own volition. Animals shall not be herded away or harassed into leaving. Specifically, the animals must not be intentionally approached by project watercraft. If the animal(s) is not sighted a second time, the event may resume 30 minutes after the last sighting.

6. The observers and contractors shall evaluate any problems encountered during blasting events and logistical solutions shall be presented to the Contracting Officer. Corrections to the watch shall be made prior to the next blasting event. If any one of the aforementioned conditions is not met prior to or during the blasting, the watch observers shall have the authority to terminate the blasting event, until resolution can be reached with Contracting Officer. The Contracting Officer will contact FWC, USFWS and NMFS.

7. If an injured or dead marine mammal or marine reptile is sighted after the blast event, the watch observers shall contact the Corps of Engineers and the Corps of Engineers will contact the resource agencies at the following phone numbers:

(1) FWC through the Manatee Hotline: 1-888-404-FWCC and 850-922-4300 (manatees).

(2) USFWS Jacksonville: 904-731-3336 (manatee)

(3) NMFS SERO-PRD: 727-824-5301 (sea turtles, whales, dolphin, sturgeon and sawfish)

(4) NMFS- Emergency Stranding Hotline – 1-877-433-8299

The observers shall maintain contact with the injured or dead mammal or reptile until authorities arrive. Blasting shall be postponed until consultations are completed and determinations can be made of the cause of injury or mortality. If blasting injuries are documented, all demolition activities shall cease. The Corps will then submit a revised plan to FWC, NMFS and USFWS for review.

18. PROTECTION MEASURES FOR COMMERCIAL STRUCTURES

The following locations can be protected from any adverse effects of blast vibration by using the vibration to construct a site specific propagation law and used deck loading of blastholes to control vibration for the following commercial structures: Cruise Ship terminal, MOL Terminal, Dames Point Bulk Terminal, **Blount Island Facilities**
The blasting contractor needs to know the distance from the structures to the blasting area to determine the conservative explosive load per delay to stay with safe vibration limits. Air overpressure from blasts in 40 feet of water should not be of concern.

19. ENVIRONMENTAL PROTECTION PROGRAM SUMMARY

This early research greatly overestimated the effects of blasting for harbor deepening projects. Recent research conducted by the USACE in New York on the Kill van Kull project in 2003 greatly reduced the safe zone radius surrounding underwater harbor deepening blasting projects.

KVK did not include any analysis for marine mammals - it was solely fishes. Miami looked at sea turtles, manatee and bottlenose dolphins, but did not mention sawfish or whales.

Based on this and other research it would be reasonable to compare the 62 pound explosive charges in boreholes to three quarter pound charges in open water. The pressures and safe zones would be reduced accordingly. While this may be true, as a conservative measure, the open water equations should be used until site specific data is generated to limit interactions with protected species.

The USACE research (2003) would reduce the charges in blastholes by a factor of 0.014 for the charge weights when calculating the shock pressures in water and the safe zones around the blast. A 62 pound charge in a stemmed blasthole would produce a pressure wave equivalent to 62 x 0.014 = 0.87 pounds of explosive in open water and a safe zone of about 140 feet around the blast area.

The older research data and equations, in open water blasts, for calculating safe zones could be used as a guideline for harbor deepening projects if the explosive weight per delay was reduced by a factor of 0.014 in the open water calculations.

CONCLUSIONS FOR SAFE DISTANCES FROM SHOCK IN WATER

Recent research By the USACE and others indicates that the safe zone radius and caution zone radius currently used is extremely conservative. These conservative values should be revisited in light of the new data and research. It has been known for decade that Navy Diver Equations and safety zone calculations have been designed for explosive detonations in open water and not explosives confined in boreholes.

The author would suggest that the methods currently used by USACE Jacksonville District be placed in the specifications along with an either/or statement that measured pressures can be used in Lieu of the Current USACE requirements. The actual measured pressure value of 40 psi would be the alternative. If the contractor wants to calibrate the project by taking actual pressure measurements from actual blast the safe zone and caution zone radius could be reduced.

20. BLASTING PATTERNS FOR JACKSONVILLE HARBOR

The blasting patterns for the largest diameter hole that can be drilled from a barge is with the drill boat Apache. The drill boat has in the past drilled holes as large as 4.5 inches in diameter for harbor deepening projects.

Figure 20.1 Drill Barge Apache

SELECTION OF EXPLOSIVES

The explosive commonly used in the past was a watergel (originally called Pourvex) explosive manufactured by Dupont, and later owners of that technology such as ETI and Dyno. The reason that this watergel was used is because Emulsion explosives commonly leave a "sheen" of carbon ofloating on the water immediatelly after the blast. This "sheen" had been mistaken for oil sheen and that is why emulsions were not used.

This old generation of watergel is no longer manufactures and emulsion explosives are used. For example the Panama Canal uses emulsion for underwater blasting.

The explosive may be a pumpable emulsion blasting agent or a cartridged emulsion blasting agent.

SELECTION OF INITIATORS

The initiator of choice for underwater blasting had been Detaline. This Dupont/ETI/Dyno product was used because of ease of hook-up oon the side of a drill barge and also because the 1.8 grain load detonating cord destroyed intself during detonation.

Detaline is no longer manufactured and the only real choice today would be to use shock tube. Shock tube was not used in the past because this approximately one eight inch diameter platic tube of lengths of at least 40 feet will remain after detonation and could foul ship or boat properrors and also be consumed by marine life. Shock tube is used on the ongoing underwater deepening projects on the Panama Canal.

Either each blasthole or each deck of explosive in the blasthole is delayed with non-electric delay blasting caps.

DESIGN OF BLASTING PATTERNS

Blast designs and the use of burden, spacing equations previously discussed are used in underwater blasting for decade.

The subdrilling is normally deeper in underwater blasting and increase to 0.5 x burdens to 0.7 x burdens in depth. This is important so that high spots are minimized.

The stemming in deep water blasting where the water column is 40 feet or more as it would be in Jacksonville harbor is reduced to 0.2 x burden in length or greater. The 40 feet of water replaces some of the confinement normally produced by the stemming.

The stemming material is commonly clean crushed stone of 0.5 to 0.75 in diameter. This stone should easily flow through the drill pipe and into the collar of the blasthole.The drill pattern would be about 10 feet by 10 feet.

Blasting patterns that have been used successfully on underwater harbor deepening projects are shown below.

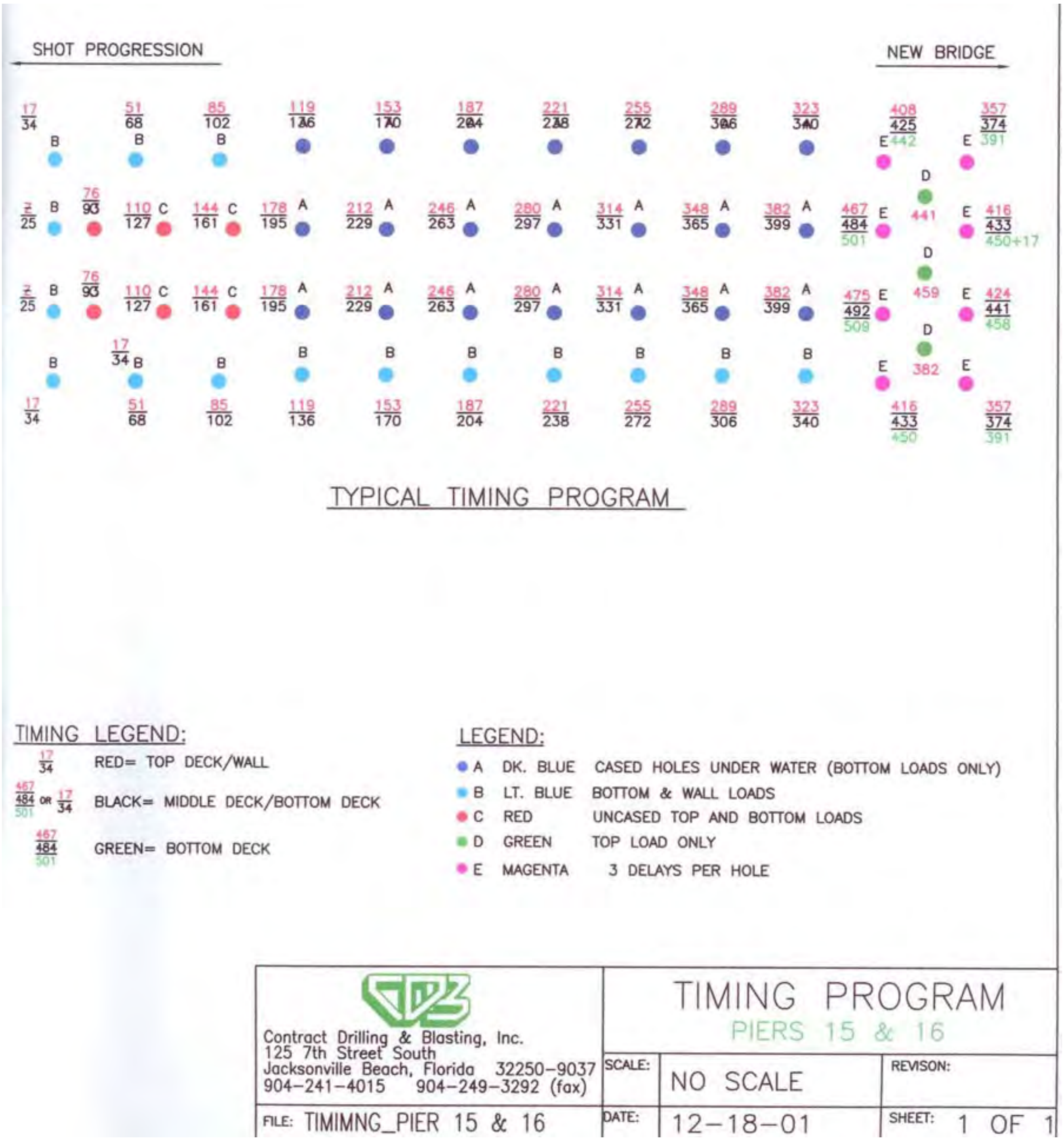


Figure 20.2 Typical Timing Pattern

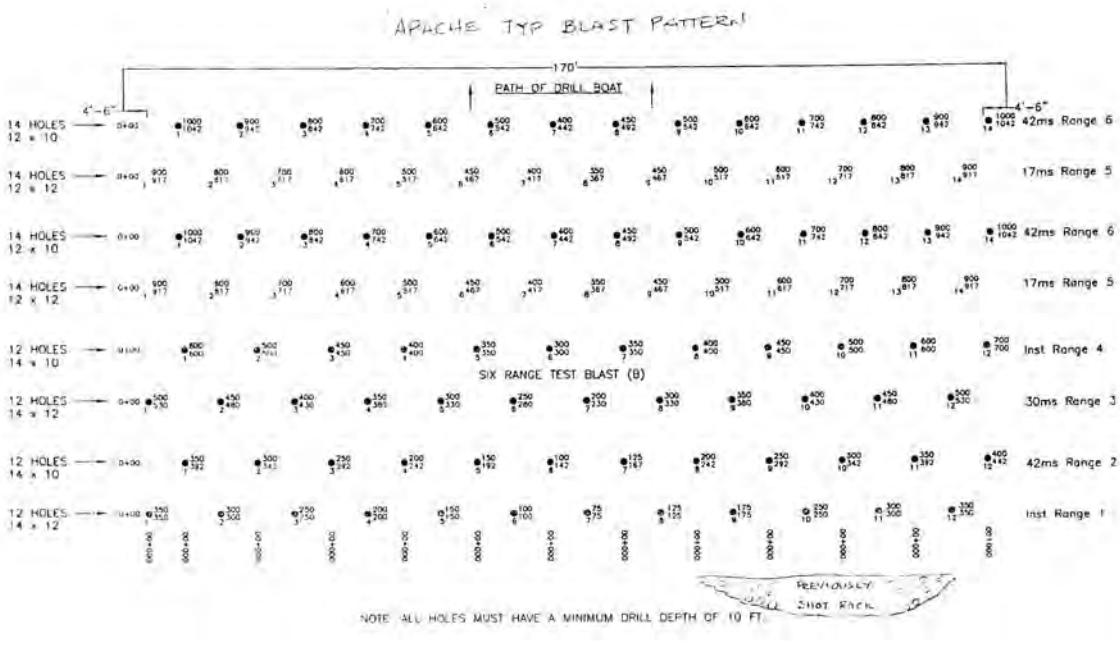


Figure 20.3 Typical Blast Pattern with Two Decks

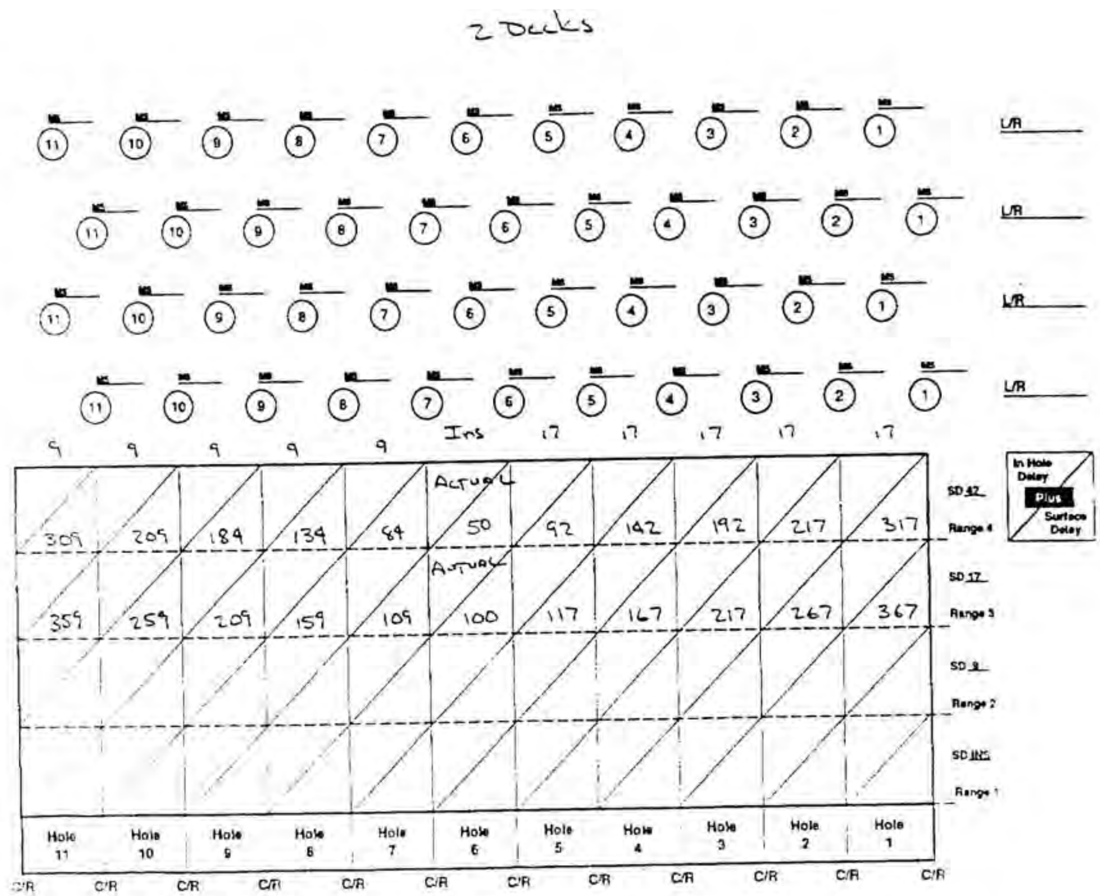


Figure 20.4 Typical Blast Pattern with Two Decks

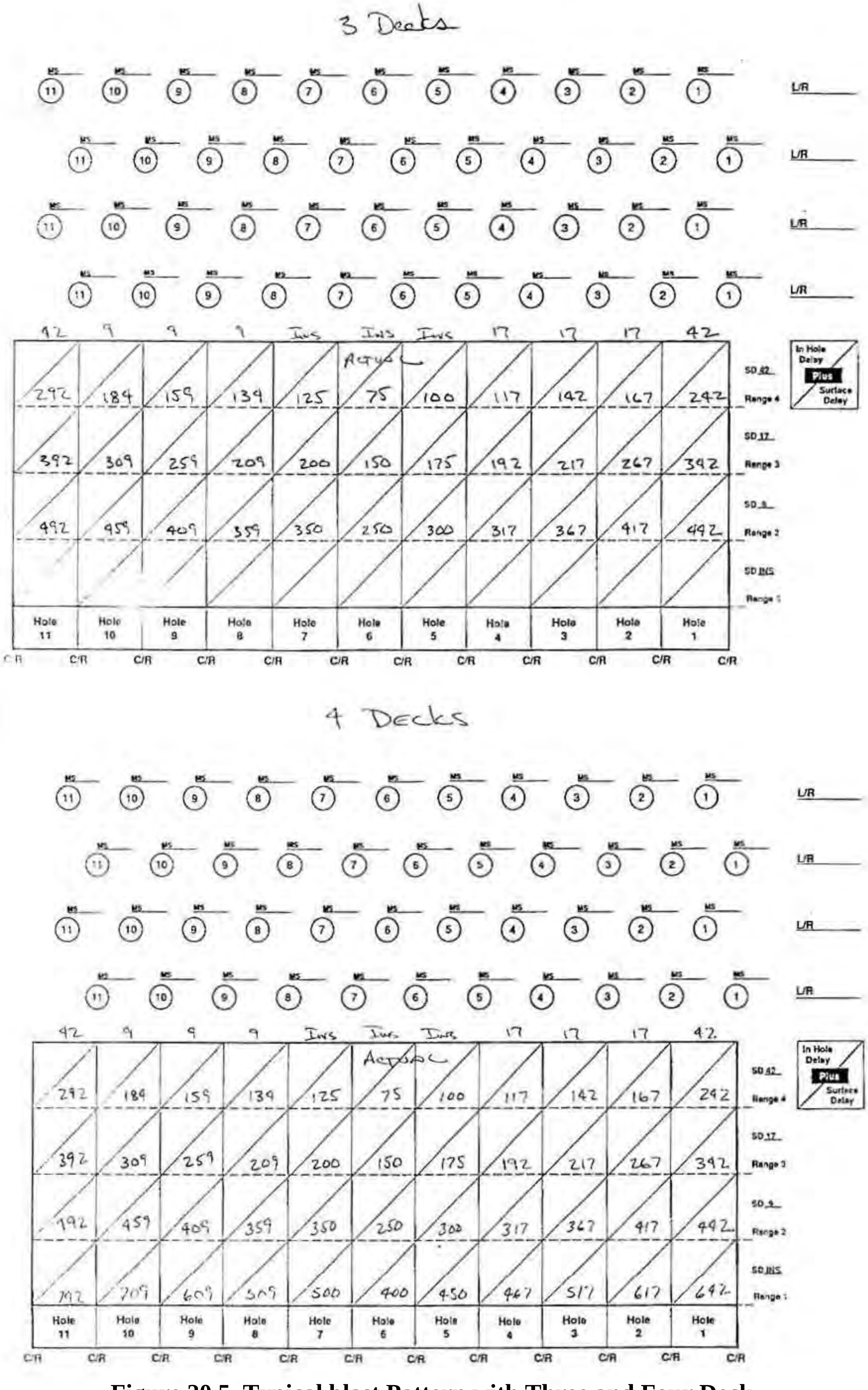


Figure 20.5 Typical blast Pattern with Three and Four Deck

21. ANTICIPATED BLAST VIBRATION LEVELS

The distance from the edge of the channel to homes and business in general is at minimum from 250 feet to 500 feet to the closest blasthole. The channel is about 500 feet wide or wider. In most cases if the largest blasthole was used and loaded with explosive the explosives load per deck is given in the table below.

The maximum length of blasthole would be about 15 feet with about 2 feet minimum stemming per blasthole. This would result in the maximum explosive length of 13 feet.

If 2.5 feet long decks of inert stemming were used between explosive charges in a blast hole then for a 15 foot deep hole the charge per deck would be 5.3 feet long. If three decks of explosive were used then each deck would be 2.7 feet long. If four decks of explosive were used then each deck would be 1.8 feet long.

The Table 21.1 below shows the anticipated vibration level (PPV) in Limestone at 250 and at 500 feet for the use of a solid column to four decks of explosive per blasthole.

A solid column of explosive for the longest possible blasthole that is 4.5 inches in diameter and bulk loaded with emulsion would produce a vibration level of about 1.0 inches per second at 250 feet from the blast. Using two decks of explosive would produce about 0.5 inches per second at the same distance. Controlling vibration with the use of delays and deck loading should be no problem.

Tables 21.2 and table 21.3 can be used to estimate vibration levels at any distance and charge weight per delay.

TABLE 21.1 EXPECTED VIBRATION LEVELS

Explosive Decks	1	2	3	4
Deck Length (ft)	15	5.3	2.7	1.8
Deck weight (lb)	112	45.6	23.2	15.5
PPV at 250 ft, Lst (ips)	1.02	0.50	0.29	0.10
PPV at 500 ft, Lst (ips)	0.34	0.16	0.10	0.06

TABLE 21.2 TYPICAL VIBRATIONS FOR EXPLOSIVE CHARGES IN LIMESTONE

Exp/Delay (Lb)	Distance (ft)	K	Beta	Vibration (ppv)	Exp/Delay (Lb)	Distance (ft)	K	Beta	Vibration (ppv)
5	100	160	-1.6	0.366	25	100	160	-1.6	1.326
5	200	160	-1.6	0.121	25	200	160	-1.6	0.437
5	300	160	-1.6	0.063	25	300	160	-1.6	0.229
5	400	160	-1.6	0.040	25	400	160	-1.6	0.144
5	500	160	-1.6	0.028	25	500	160	-1.6	0.101
5	600	160	-1.6	0.021	25	600	160	-1.6	0.075
5	700	160	-1.6	0.016	25	700	160	-1.6	0.059
5	800	160	-1.6	0.013	25	800	160	-1.6	0.048
5	900	160	-1.6	0.011	25	900	160	-1.6	0.039
5	1000	160	-1.6	0.009	25	1000	160	-1.6	0.033
10	100	160	-1.6	0.637	30	100	160	-1.6	1.534
10	200	160	-1.6	0.210	30	200	160	-1.6	0.506
10	300	160	-1.6	0.110	30	300	160	-1.6	0.264
10	400	160	-1.6	0.069	30	400	160	-1.6	0.167
10	500	160	-1.6	0.049	30	500	160	-1.6	0.117
10	600	160	-1.6	0.036	30	600	160	-1.6	0.087
10	700	160	-1.6	0.028	30	700	160	-1.6	0.068
10	800	160	-1.6	0.023	30	800	160	-1.6	0.055
10	900	160	-1.6	0.019	30	900	160	-1.6	0.046
10	1000	160	-1.6	0.016	30	1000	160	-1.6	0.039
15	100	160	-1.6	0.881	35	100	160	-1.6	1.735
15	200	160	-1.6	0.291	35	200	160	-1.6	0.572
15	300	160	-1.6	0.152	35	300	160	-1.6	0.299
15	400	160	-1.6	0.096	35	400	160	-1.6	0.189
15	500	160	-1.6	0.067	35	500	160	-1.6	0.132
15	600	160	-1.6	0.050	35	600	160	-1.6	0.099
15	700	160	-1.6	0.039	35	700	160	-1.6	0.077
15	800	160	-1.6	0.032	35	800	160	-1.6	0.062
15	900	160	-1.6	0.026	35	900	160	-1.6	0.052
15	1000	160	-1.6	0.022	35	1000	160	-1.6	0.044
20	100	160	-1.6	1.109	40	100	160	-1.6	1.931
20	200	160	-1.6	0.366	40	200	160	-1.6	0.637
20	300	160	-1.6	0.191	40	300	160	-1.6	0.333
20	400	160	-1.6	0.121	40	400	160	-1.6	0.210
20	500	160	-1.6	0.084	40	500	160	-1.6	0.147
20	600	160	-1.6	0.063	40	600	160	-1.6	0.110
20	700	160	-1.6	0.049	40	700	160	-1.6	0.086
20	800	160	-1.6	0.040	40	800	160	-1.6	0.069
20	900	160	-1.6	0.033	40	900	160	-1.6	0.057
20	1000	160	-1.6	0.028	40	1000	160	-1.6	0.049

TABLE 21.3 TYPICAL VIBRATIONS FOR EXPLOSIVE CHARGES IN LIMESTONE

Exp/Delay	Distance	K	Beta	Vibration	Exp/Delay	Distance	K	Beta	Vibration
50	100	160	-1.6	2.308	80	100	160	-1.6	3.362
50	200	160	-1.6	0.761	80	200	160	-1.6	1.109
50	300	160	-1.6	0.398	80	300	160	-1.6	0.580
50	400	160	-1.6	0.251	80	400	160	-1.6	0.366
50	500	160	-1.6	0.176	80	500	160	-1.6	0.256
50	600	160	-1.6	0.131	80	600	160	-1.6	0.191
50	700	160	-1.6	0.103	80	700	160	-1.6	0.149
50	800	160	-1.6	0.083	80	800	160	-1.6	0.121
50	900	160	-1.6	0.069	80	900	160	-1.6	0.100
50	1000	160	-1.6	0.058	80	1000	160	-1.6	0.084
60	100	160	-1.6	2.671	90	100	160	-1.6	3.694
60	200	160	-1.6	0.881	90	200	160	-1.6	1.219
60	300	160	-1.6	0.461	90	300	160	-1.6	0.637
60	400	160	-1.6	0.291	90	400	160	-1.6	0.402
60	500	160	-1.6	0.203	90	500	160	-1.6	0.281
60	600	160	-1.6	0.152	90	600	160	-1.6	0.210
60	700	160	-1.6	0.119	90	700	160	-1.6	0.164
60	800	160	-1.6	0.096	90	800	160	-1.6	0.133
60	900	160	-1.6	0.079	90	900	160	-1.6	0.110
60	1000	160	-1.6	0.067	90	1000	160	-1.6	0.093
70	100	160	-1.6	3.021	100	100	160	-1.6	4.019
70	200	160	-1.6	0.997	100	200	160	-1.6	1.326
70	300	160	-1.6	0.521	100	300	160	-1.6	0.693
70	400	160	-1.6	0.329	100	400	160	-1.6	0.437
70	500	160	-1.6	0.230	100	500	160	-1.6	0.306
70	600	160	-1.6	0.172	100	600	160	-1.6	0.229
70	700	160	-1.6	0.134	100	700	160	-1.6	0.179
70	800	160	-1.6	0.108	100	800	160	-1.6	0.144
70	900	160	-1.6	0.090	100	900	160	-1.6	0.119
15	1000	160	-1.6	0.022	100	1000	160	-1.6	0.101
20	100	160	-1.6	1.109	110	100	160	-1.6	4.337
20	200	160	-1.6	0.366	110	200	160	-1.6	1.431
20	300	160	-1.6	0.191	110	300	160	-1.6	0.748
20	400	160	-1.6	0.121	110	400	160	-1.6	0.472
20	500	160	-1.6	0.084	110	500	160	-1.6	0.330
20	600	160	-1.6	0.063	110	600	160	-1.6	0.247
20	700	160	-1.6	0.049	110	700	160	-1.6	0.193
20	800	160	-1.6	0.040	110	800	160	-1.6	0.156
20	900	160	-1.6	0.033	110	900	160	-1.6	0.129
20	1000	160	-1.6	0.028	110	1000	160	-1.6	0.109

22. EXPLOSIVES AND BLASTING REGULATIONS FOR REGION

The explosives and blasting regulations that would influence this project are given below.

JACKSONVILLE AND DUVAL COUNTY CODE.

1. **552.081 f.s.**
Score: 89.09%

Abstract: “Explosive materials” means —As used in this chapter:(1) “User” means a dealer or explosives, blasting agents, or detonators. (8) manufacturer-distributor who uses an explosive as an ultimate consumer or a person who, as an ultimate consumer of an explosive, purchases such explosive “Blaster” means a person employed from a dealer or manufacturer-distributor. (9) by a user who detonates or otherwise effects the explosion of an explosive.

2. **552.30 f.s.**
Score: 83.47%

Abstract: 552.25, the State Fire Marshal shall have the sole and exclusive authority to promulgate standards, limits, and regulations regarding the use of explosives in conjunction with construction materials mining The State Fire Marshal shall establish statewide ground activities. (2) vibration limits for construction materials mining activities which conform to those limits established in the United States Bureau of Mines, Report of Investigations 8507, Appendix B - Alternative Blasting ...

3. **552.112 f.s.**
Score: 83.47%

Abstract: It is unlawful for any user of explosives to purchase, —(1) store, or use explosives without maintaining an accurate and current written Such inventory of all explosives purchased, possessed, stored, or used. (2) records shall include, but not be limited to, invoices or sales tickets from purchases, location of blasting sites, dates and times of firing, the amount of explosives used for each blast or delay series, the name of the person in charge of loading and firing, ...

4. **791.04 f.s.**
Score: 79.67%

Abstract: Sale at wholesale, etc., exempted.— Nothing in this 791.04 chapter shall be construed to prohibit any manufacturer, distributor, or wholesaler who has registered with the division pursuant to s. 791.015 to sell at wholesale such fireworks as are not herein prohibited; to prohibit the sale of any kind of fireworks at wholesale between manufacturers, distributors, and wholesalers who have registered with the division pursuant to s. 791.015; to prohibit the sale of any kind of ...

5. **769.01 f.s.**
Score: 79.67%

Abstract: Employers affected by fellow servant act.— This 769.01 chapter shall apply to

	persons engaged in the following hazardous occupations in this state; namely, railroading, operating street railways, generating and selling electricity, telegraph and telephone business, express business, blasting and dynamiting, operating automobiles for public use, boating, when boat is propelled by steam, gas or electricity. 6521, 1913; RGS 4971; CGL 7058.
6. **552.34 f.s.** **Score:** 79.67%	**Abstract:** Construction —The Legislature finds and declares that:(1) materials mining activities require the use of explosives to fracture the The use of explosives results in physical material prior to excavation. (2) ground vibrations and air blasts that may affect other property owners in the It is in the best interests of the public to vicinity of the mining site. (3) provide a specific administrative remedy for complaints related to the use of explosives in construction ...
7. **790.001 f.s.** **Score:** 77.42%	**Abstract:** “Concealed weapon” means any dirk, metallic (3)(a) knuckles, slungshot, billie, tear gas gun, chemical weapon or device, or other deadly weapon carried on or about a person in such a manner as to conceal the “Tear gas gun” or weapon from the ordinary sight of another person. (b) “chemical weapon or device” means any weapon of such nature, except a device “Weapon” means any dirk, knife, known as a “self-defense chemical spray. (13) metallic knuckles, slungshot, billie, ...
8. **633.021 f.s.** **Score:** 77.42%	**Abstract:** Such systems include, but are not limited to, water sprinkler systems, water spray systems, foam-water sprinkler systems, foam-water spray systems, CO2 systems, foam extinguishing systems, dry chemical systems, and Halon and other chemical systems used for fire protection use. Such systems also include any overhead and underground fire mains, fire hydrants and hydrant mains, standpipes and hoses connected to sprinkler systems, sprinkler tank heaters, air lines, thermal systems used in ...
9. **212.06 f.s.** **Score:** 77.42%	**Abstract:** Sales, storage, use tax; collectible from dealers; 212.06 “dealer” defined; dealers to collect from purchasers; legislative intent as to The term “dealer,” as used in this chapter, includes every scope of tax. (2)(a) person who manufactures or produces tangible personal property for sale at retail; for use, consumption, or distribution; or for storage to be used or In furtherance of this act, dealers selling tangible consumed in this state. personal property for delivery...

1. 552.081 f.s.Score: 89.09%
  Abstract: —As used in this chapter:(1) “Explosive materials” means explosives, blasting agents, or detonators. (8) “User” means a dealer or manufacturer-distributor who uses an explosive as an ultimate consumer or a person who, as an ultimate consumer of an explosive, purchases such explosive from a dealer or manufacturer-distributor. (9) “Blaster” means a person employed by a user who detonates or otherwise effects the explosion of an explosive.

2. 552.30 f.s.
Score: 83.47%
  Abstract: 552.25, the State Fire Marshal shall have the sole and exclusive authority to promulgate standards, limits, and regulations regarding the use of explosives in conjunction with construction materials mining activities. (2) The State Fire Marshal shall establish statewide ground vibration limits for construction materials mining activities which conform to those limits established in the United States Bureau of Mines, Report of Investigations 8507, Appendix B - Alternative Blasting ...

3. 552.112 f.s.
Score: 83.47%
  Abstract: —(1) It is unlawful for any user of explosives to purchase, store, or use explosives without maintaining an accurate and current written inventory of all explosives purchased, possessed, stored, or used. (2) Such records shall include, but not be limited to, invoices or sales tickets from purchases, location of blasting sites, dates and times of firing, the amount of explosives used for each blast or delay series, the name of the person in charge of loading and firing, ...

4. 791.04 f.s.
Score: 79.67%
  Abstract: 791.04 Sale at wholesale, etc., exempted.—Nothing in this chapter shall be construed to prohibit any manufacturer, distributor, or wholesaler who has registered with the division pursuant to s. 791.015 to sell at wholesale such fireworks as are not herein prohibited; to prohibit the sale of any kind of fireworks at wholesale between manufacturers, distributors, and wholesalers who have registered with the division pursuant to s. 791.015; to prohibit the sale of any kind of ...

5. 769.01 f.s.
Score: 79.67%
  Abstract: 769.01 Employers affected by fellow servant act. —This chapter shall apply to persons engaged in the following hazardous occupations in this state; namely, railroading, operating street railways, generating and selling electricity, telegraph and telephone business, express business, blasting and dynamiting, operating automobiles for public use, boating, when boat is propelled by steam, gas or electricity. 6521, 1913; RGS 4971; CGL 7058.

6. 552.34 f.s.
Score: 79.67%
Abstract: —The Legislature finds and declares that:(1) Construction materials mining activities require the use of explosives to fracture the material prior to excavation. (2) The use of explosives results in physical ground vibrations and air blasts that may affect other property owners in the vicinity of the mining site. (3) It is in the best interests of the public to provide a specific administrative remedy for complaints related to the use of explosives in construction ...

7. 790.001 f.s.
Score: 77.42%
Abstract: (3)(a) "Concealed weapon" means any dirk, metallic knuckles, slungshot, billie, tear gas gun, chemical weapon or device, or other deadly weapon carried on or about a person in such a manner as to conceal the weapon from the ordinary sight of another person. (b) "Tear gas gun" or "chemical weapon or device" means any weapon of such nature, except a device known as a "self-defense chemical spray. (13) "Weapon" means any dirk, knife, metallic knuckles, slungshot, billie, ...

JACKSONVILLE MUNICODE

Sec. 420.213. - Explosives, blasting agents and ammunition; permits and bonds required.

(a)Permits shall be obtained:

(1)To manufacture, possess, store, sell or otherwise dispose of explosives, blasting agents or small arms ammunition.

(2)To transport explosives or blasting agents.

(3)To use explosives or blasting agents.

(4)To operate a terminal for handling explosives or blasting agents.

(5)To deliver to or receive explosives or blasting agents from a carrier at a terminal between the hours of sunset and sunrise.

(6)To transport blasting caps or electric blasting caps on the same vehicle with explosives.

(b)Permits required by subsection (a)(1) of this Section shall not be issued for:

(1)Liquid nitroglycerin.

(2)Dynamite (except gelatin dynamite) containing over 60 percent of liquid explosive ingredient.

(3)Dynamite having an unsatisfactory absorbent or one that permits leakage of a liquid explosive ingredient under any conditions liable to exist during storage.

(4)Nitrocellulose in a dry and uncompressed condition in quantity greater than ten pounds net weight in one package.

(5)Fulminate of mercury in a dry condition and fulminate of all other metals in any condition except as a component of manufactured articles not hereinafter forbidden.

(6)Explosive compositions that ignite spontaneously or undergo marked decomposition, rendering the products or their use more hazardous when subjected to 48 consecutive hours or less to a temperature of 167 degrees Fahrenheit.

(7)New explosives until approved by the United States Department of Transportation, except that permits may be issued to educational, governmental or industrial laboratories for instructional or research purposes.

(8)Explosives condemned by the United States Department of Transportation.

(9)Explosives not packed or marked in accordance with the requirements of the United States Department of Transportation.

(10)Explosives containing an ammonium salt and a chlorate.

(c)Before a permit is issued as required by Section 420.213(a)(3), the applicant shall file with the Chief, Fire Prevention a corporate surety bond in the principal sum of $100,000 or a public liability insurance policy for the same amount, for the purpose of the payment of all damages to persons or property which arise from, or are caused by, the conduct of any act authorized by the permit. The Chief, Fire Prevention may specify a greater or lesser amount when, in his opinion, conditions at the location of use indicate a greater or lesser amount is required.

(d)As used in this Section the terms blasting agent, carrier, explosive, small arms ammunition, and terminal shall have the same meaning as those terms have in the *Standard Fire Prevention Code* adopted by Section 321.104.

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1. **552.081 f.s.** **Score:** 89.09%

   Abstract: “Explosive materials” means —As used in this chapter:(1) “User” means a dealer or explosives, blasting agents, or detonators. (8) manufacturer-distributor who uses an explosive as an ultimate consumer or a person who, as an ultimate consumer of an explosive, purchases such explosive “Blaster” means a person employed from a dealer or manufacturer-distributor. (9) by a user who detonates or otherwise effects the explosion of an explosive.

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Score: 79.67%

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Score: 79.67%

Abstract: Employers affected by fellow servant act. —This 769.01 chapter shall apply to persons engaged in the following hazardous occupations in this state; namely, railroading, operating street railways, generating and selling electricity, telegraph and telephone business, express business, blasting and dynamiting, operating automobiles for public use, boating, when boat is propelled by steam, gas or electricity. 6521, 1913; RGS 4971; CGL 7058.

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Abstract: “Concealed weapon” means any dirk, metallic(3)(a) knuckles, slungshot, billie, tear gas gun, chemical weapon or device, or other deadly weapon carried on or about a person in such a manner as to conceal the “Tear gas gun” or weapon from the ordinary sight of another person. (b) “chemical weapon or device” means any weapon of such nature, except a device “Weapon” means any dirk, knife, known as a “self-defense chemical spray. (13) metallic knuckles, slungshot, billie, ...

8. **633.021 f.s.**
Score: 77.42%

Abstract: Such systems include, but are not limited to, water sprinkler systems, water spray systems, foam-water sprinkler systems, foam-water spray systems, CO2 systems, foam extinguishing systems, dry chemical systems, and Halon and other chemical systems used for fire protection use. Such systems also include any overhead and underground fire mains, fire hydrants and hydrant mains, standpipes and hoses connected to sprinkler systems, sprinkler tank heaters, air lines, thermal systems used in ...

9. **212.06 f.s.**
Score: 77.42%

Abstract: Sales, storage, use tax; collectible from dealers; 212.06 "dealer" defined; dealers to collect from purchasers; legislative intent as to The term "dealer," as used in this chapter, includes every scope of tax. (2)(a) person who manufactures or produces tangible personal property for sale at retail; for use, consumption, or distribution; or for storage to be used or In furtherance of this act, dealers selling tangible consumed in this state. personal property for delivery...

552.081 f.s.
Score: 89.09%
Abstract: —As used in this chapter:(1) "Explosive materials" means explosives, blasting agents, or detonators. (8) "User" means a dealer or manufacturer-distributor who uses an explosive as an ultimate consumer or a person who, as an ultimate consumer of an explosive, purchases such explosive from a dealer or manufacturer-distributor. (9) "Blaster" means a person employed by a user who detonates or otherwise effects the explosion of an explosive.

2. 552.30 f.s.
Score: 83.47%
Abstract: 552.25, the State Fire Marshal shall have the sole and exclusive authority to promulgate standards, limits, and regulations regarding the use of explosives in conjunction with construction materials mining activities. (2) The State Fire Marshal shall establish statewide ground vibration limits for construction materials mining activities which conform to those limits established in the United States Bureau of Mines, Report of Investigations 8507, Appendix B - Alternative Blasting ...

3. 552.112 f.s.
Score: 83.47%
Abstract: —(1) It is unlawful for any user of explosives to purchase, store, or use explosives without maintaining an accurate and current written inventory of all explosives purchased, possessed, stored, or used. (2) Such records shall include, but not be limited to, invoices or sales tickets from purchases, location of blasting sites, dates and times of firing, the amount of explosives used for each blast or delay series, the name of the person in charge of loading and firing, ...

4. 791.04 f.s.
Score: 79.67%
Abstract: 791.04 Sale at wholesale, etc., exempted.—Nothing in this chapter shall be construed to prohibit any manufacturer, distributor, or wholesaler who has registered with the division pursuant to s. 791.015 to sell at wholesale such fireworks as are not herein prohibited; to prohibit the sale of any kind of fireworks at wholesale between manufacturers, distributors, and wholesalers who have registered with the division pursuant to s. 791.015; to prohibit the sale of any kind of ...

5. 769.01 f.s.
Score: 79.67%
Abstract: 769.01 Employers affected by fellow servant act. —This chapter shall apply to persons engaged in the following hazardous occupations in this state; namely, railroading, operating street railways, generating and selling electricity, telegraph and telephone business, express business, blasting and dynamiting, operating automobiles for public use, boating, when boat is propelled by steam, gas or electricity. 6521, 1913; RGS 4971; CGL 7058.

6. 552.34 f.s.
Score: 79.67%
Abstract: —The Legislature finds and declares that:(1) Construction materials mining activities require the use of explosives to fracture the material prior to excavation. (2) The use of explosives results in physical ground vibrations and air blasts that may affect other property owners in the vicinity of the mining site. (3) It is in the best interests of the public to provide a specific administrative remedy for complaints related to the use of explosives in construction ...

7. 790.001 f.s.
Score: 77.42%
Abstract: (3)(a) “Concealed weapon” means any dirk, metallic knuckles, slungshot, billie, tear gas gun, chemical weapon or device, or other deadly weapon carried on or about a person in such a manner as to conceal the weapon from the ordinary sight of another person. (b) “Tear gas gun” or “chemical weapon or device” means any weapon of such nature, except a device known as a “self-defense chemical spray. (13) “Weapon” means any dirk, knife, metallic knuckles, slungshot, billie, ...

FLORIDA STATE FIRE MARSHALS

69A-2.024 Construction Materials Mining Activities.

(1) Scope.

(a) This section implements Section 552.30, F.S., which gives the State Fire Marshal sole and exclusive authority to promulgate standards, limits, and regulations regarding the use of explosives in conjunction with the extraction of limestone and sand by any person or company primarily engaged in commercial mining of limestone and sand suitable for production of construction aggregates, sand, cement, and road base materials and Section 552.211, F.S., which allows the State Fire Marshal to restrict the quantity and use of explosives at any location within the state where such explosive is likely to cause injury to life or property.

(b) Any person or company not primarily engaged in commercial mining of limestone and sand suitable for production of construction aggregates, sand, cement, and road base materials remains subject to the provisions of Section 552.25, F.S.

(c) Nothing in this section is intended to supercede the requirements of Chapter 552, F.S., or other sections in this rule chapter.

(2) Definitions. As used in this rule:

(a) "Blasting site" is a location within a mining area at which explosive charges are set.

(b) "Independent seismologist" is an individual whose function includes vibration and air overpressure measurement and the analysis and evaluation of their effects upon structures.

1. A seismologist under this subsection will not be considered "independent" if the seismologist is an employee of:

a. The mining permit holder, blaster, or user; or

b. Any entity subject to regulation under Section 552.30, F.S.

2. A seismologist shall be ineligible to serve as an "independent seismologist" if the seismologist:

a. Has within 2 years from the written notice referenced below been retained by or otherwise served as an expert witness, investigator, or consultant for the mining permit holder, blaster, or user or for an aggrieved party in connection with any anticipated or threatened claim, legal action, or other proceedings in which the mining permit holder, blaster, or user is alleged in a written notice to have caused damages or adversely affected personal property allegedly due to the operation or performance of the activities regulated under this rule chapter; or

b. Does not meet the criteria of paragraph (4)(c) of this rule.

3. The Fire Marshal's office shall provide a list of qualified independent seismologists approved for use pursuant to this paragraph. The requirement to use an independent seismologist shall not be effective until the list is compiled.

(c) "Limestone" as used in Section 552.30(1), F.S., means any extracted material composed principally of calcium or magnesium carbonate. Coquina is a form of limestone composed of shell fragments.

(d) "Mining area" as used in this rule section is the area of land in which construction materials mining activity is to occur.

(e) "Urban development" is defined as a residential subdivision containing 25 or more occupied residences within the local urban development boundary.

(3) Mining Permit.

(a) Applicability.

1. Any construction materials mining activity which is in operation upon the effective date of this rule shall be allowed to continue such mining operations, including blasting, provided that the applicant submits an application in accordance with this rule within 90 days of the effective date of this rule.

2. All construction materials mines which are not in active operation on the effective date of this rule must have a blasting permit issued pursuant to these rules prior to commencing blasting activities.

(b) A mining permit shall be issued only after:

1. Payment of a fee established in subsection (10) below or by the county or municipality to cover costs.

2.a. Approval of an application, signed by the applicant showing the applicant's name and address, on Form DI4-1498 Rev. 3/02, Construction Mining Activity Application, which is hereby adopted and incorporated by reference and is available from Safety Program Manager, Bureau of Fire Prevention, Division of State Fire Marshal, 200 East Gaines Street, Tallahassee, Florida 32399-0342.

b. Within 30 days of receipt of the application, the State Fire Marshal shall request additional information if necessary to evaluate the application.

c. The State Fire Marshal shall inform the permittee by fax or otherwise in writing when the application is complete.

d. Within 90 days of the completion of the application, the application shall be approved or denied.

(c) The permit holder shall report all complaints to the authority issuing the permit.

(d) Standards for Mining Permit Approval. A mining permit shall be approved unless any item listed on Form DI4-1498 in paragraph (b) above is not provided.

(e) License period. Each mining permit shall be issued for a period of 10 years.

(f) Annual Report and Annual Permit Fee Procedure.

1. The mining activity covered by the mining permit will be reviewed on an annual basis for compliance with Chapter 552, F.S., including but not limited to compliance with the record keeping requirements.

2. The mining permit holder shall annually pay a permitting fee specified in subsection (10) below.

(g) Transfer of permits.

1. Within 60 days after the sale or legal transfer of a mining operation, the permittee shall inform the State Fire Marshal or delegatee in writing of the sale or legal transfer, identify the proposed new permittee, and request transfer of the permit.

2. At the option of the permittee request for transfer may be made prior to the sale or transfer of the mining operation, with approval being effective upon closing of the sale or transfer of the operation.

3. Requests for transfer shall be accompanied by the fee specified in paragraph (10)(e).

4. The State Fire Marshal or delegatee shall approve the transfer of the permit unless it determines that the proposed new permittee does not meet the requirements of this rule. The determination shall be limited solely to the ability of the new permittee to comply with the conditions of the existing permit, and it shall not concern the adequacy of the permit conditions.

5. Within 30 days of receipt of the request for a transfer, the State Fire Marshal or delegatee shall request additional information if necessary to evaluate the request. The State Fire Marshal or delegatee shall inform the permittee by fax or otherwise in writing when the request is complete.

6. Within 90 days of the completion of the request, the request shall be approved or denied subject to Section 120.60, F.S.

7. The transferee is allowed to continue to operate under the existing permit until the request for transfer has been approved or denied.

(h) Renewal of Permits.

1. At least 60 days prior to the expiration of a mining permit issued pursuant to this rule, the permittee wishing to continue activities subject to this rule shall apply for renewal of the permit using Form DI4-1498, Construction Mining Activity Application.

2. If the request is submitted at least 60 days prior to the expiration of the mining permit, the existing permit shall remain in effect until final agency action, or later as required by Section 120.60, F.S.

(i) Modification of Permits.

1. A permittee may request a modification of the permit by applying to the State Fire Marshal or delegatee. The request shall identify the proposed modification.

2. Requests for modification shall be accompanied by the fee specified in paragraph (10)(d).

3. Within 30 days of receipt of the request, the State Fire Marshal or delegatee shall request additional information if necessary to evaluate the request.

4. The State Fire Marshal or delegatee shall inform the permittee by fax or otherwise in writing when the request is complete.

5. Within 30 days of the completion of the request, the request shall be approved or denied subject to Section 120.60, F.S.

(4) Ground Vibration Limits. Ground vibration shall not exceed the limits of particle velocity and frequencies established by the U.S. Bureau of Mines Report of Investigations, No. 8507 Ground Vibration, Frequency Limits.

(a)1. The maximum, Appendix B – Alternative Blasting Level Criteria (Figure B-1). A blasting operation shall use a seismograph, as identified in paragraph (c) below, to monitor each blast to ensure compliance with the ground vibration limits established in Section 552.30, F.S.

2. The U.S. Bureau of Mines Report of Investigations No. 8507, Appendix B – Alternative Blasting Level Criteria (Figure B-1) and Table 8-1.3, established in Section 8-1 of the National Fire Protection Association Standard 495, 1996 Edition are hereby adopted and incorporated by reference. Copies may be obtained from the Bureau of Fire Prevention, 200 East Gaines Street, Tallahassee, FL 32399-0342.

(b) 1. Ground vibration shall be measured for every blast at the location of the nearest building that is not owned, leased, or contracted by the blasting or mining operation, or on property for which the owner has not provided a written waiver to the blasting operations, up to a maximum of one mile.

2. If there are no such buildings within one mile, measurement shall be made at one mile in the direction of the nearest such building.

3. If there is a building that is not owned, leased, or contracted by the blasting or mining operation, or on property for which the owner has not provided a written waiver to the blasting operations in a direction 90 to 270 degrees from the direction of the nearest building specified in subparagraph (b)1. above, and that building is no more than 500 feet farther than the nearest building, measurement shall also be made at the nearest of those buildings.

4. If a measurement location determined pursuant to subparagraphs (b)1.-3. above is not practicable, such as in a wet swamp, measurement shall be made at a point nearer to but in the same direction from the blast site.

(c)1. All measurements shall be made by a seismologist meeting the following criteria:

a. Five years continuous experience measuring and evaluating levels of ground vibration and air overpressure produced by blasting;

b. Demonstrable expertise in the use, location, and operation of seismographic equipment and analysis of seismographic data; and

c. Prior experience in monitoring side effects produced by blasting used in construction materials mining activity.

d. The State Fire Marshal has not found that the seismologist has engaged in dishonest practices relating to the collection or analysis of data or information regarding the use of explosives in construction materials mining. Such a finding will be subject to Section 120.57, F.S.

e. The seismologist is not an employee of the mining permit holder, blaster, or user.

2. Measurements shall be taken and equipment shall meet specifications of and be installed in accordance with the International Society of Explosives Engineers Blaster's Handbook, 17th Edition, Copyright 1998.

3. The International Society of Explosives Engineers Blaster's Handbook, 17th Edition, Copyright 1998, is hereby adopted and incorporated by reference and may be obtained from the International Society of Explosives Engineers, 29100 AVRA Road, Cleveland, Ohio 44131.

4. When the use of explosives occurs within 2 miles of an urban development, measurements shall be collected and reported by an independent seismologist.

(d)1. All seismographic equipment used within the boundaries of the State of Florida shall be calibrated according to the manufacturer's specifications and shall be certified as accurate by the manufacturer on an annual basis or as needed.

2. If the manufacturer is unavailable for such certification, the certification shall be performed by a person approved by the State Fire Marshal. Such approval shall be granted if the certifying person is known to be independent and reliable. "Independent" means not an employee or affiliate of a company engaged in construction materials mining activity, and "reliable" means never having been found to have willfully or negligently miscalibrated seismographic equipment.

3. Units not meeting current calibration guidelines shall be removed from service until calibration has been completed.

4. Calibration records shall be made available to the Division upon request.

(5) Airblast.

(a) Airblast limits shall conform with the limits established in Section 8-2 of National Fire Protection Association Standard Number 495, 1996 Edition, which is hereby adopted and incorporated by reference.

1. The codes and standards published by the National Fire Protection Association may be obtained by writing to the NFPA at: 1 Batterymarch Park, Quincy, Massachusetts 02269-9101.

2. All standards adopted and incorporated by reference in this rule are also available for public inspection during regular business hours at the Bureau of Fire Prevention, Division of State Fire Marshal, Department of Financial Services, 325 John Knox Road, The Atrium, Third Floor, Tallahassee, Florida 32303.

(b)1. Measurements made by a seismologist and any measurements made by an independent seismologist shall be made using seismographic equipment meeting the specifications of the International

Society of Explosives Engineers Blasters' Handbook, 17th Edition, Copyright 1998.

2. Measurements shall be taken and equipment shall be installed in accordance with the International Society of Explosives Engineers Blasters' Handbook, 17th Edition, Copyright 1998.

(6) Time and Date of Explosives Use.

(a) The use of explosives shall be conducted during daylight hours between 8:00 a.m. and 5:00 p.m. local time, Monday through Friday.

(b) No explosive blasting shall occur on Saturdays, Sundays, official holidays recognized by the State of Florida pursuant to Section 110.117, F.S., or hours other than specified in the prior sentence unless consent is granted by the State Fire Marshal. Such consent shall be granted if the consent is in the interest of public safety.

(7) Blasting Activities Reporting. Each person engaged in construction materials mining activity shall submit to the Division or its delegatee, upon request, the results of ground vibration and airblast measurements. This report shall be maintained in accordance with Section 552.112, F.S. The report shall contain, at a minimum, for each blast:

(a) Date and time of blast;

(b) Number of holes;

(c) Depth;

(d) Number of wet holes, water depth;

(e) Hole diameter;

(f) Spacing;

(g) Amount of explosives;

(h) Number of primers;

(i) Type of caps (i.e., electric or nonelectric);

(j) Number of caps;

(k) Stemming feet;

(l) Maximum pounds delay;

(m) Maximum hole delay;

(n) Weather;

(o) Wind direction;

(p) Type and make of blasting machine;

(q) Global positioning system direction and distance in feet to the nearest building;

(r) Decking feet;

(s) Location of each seismograph;

(t) Peak particle velocity inches per second;

(u) Sound decibels;

(v) Name, address, and license number of user of explosives; and

(w) Name, address, and permit number of blaster.

(8) Local Government Notice.

(a) Each person permitted to engage in construction materials mining activity shall submit written notification to the county and or municipality in which construction materials mining activity is to be conducted. The initial and subsequent notices required by this rule shall advise that a permit has been issued or renewed. The initial notice shall be provided after the issuance of the permit and give at least 20 days notice prior to the initial blast.

(b) Subsequent notices shall be provided following the annual permit renewal date and give at least five days notice prior to the first blast following annual permit renewal date. Notice is required to be given no more than once per year.

(c) As soon as practical, but no later than one hour prior to the time when a blast is scheduled to take place, the person or firm engaged in construction materials mining activity shall, if requested, notify the county or municipality of any revisions to the notice.

(9) Delegation of Authority.

(a) The delegation by the State Fire Marshal described in Section 552.30(2), F.S., shall be accomplished by written agreement.

(b) Fees charged by the delegatee for activities specified in the agreement shall not exceed an amount calculated to cover the reasonable costs of the activities performed under the agreement.

(10) Fees. The fees established pursuant to Section 552.30, F.S., shall be used exclusively to fund the monitoring and enforcement activities pursuant to Section 552.30, F.S., unless otherwise approved by the Florida Legislature, and shall be as follows:

(a) Initial permit: $4000.

(b) Renewal: $4000 after 10 years.

(c) Annual mining permit fee: $1500.

(d) Permit transfer fee: $100.

(e) Permit modification fee:

1. $1500 for a modification including a change in the boundaries of the blasting site or mining area;

2. $500 for any other modification.

(11) Disciplinary Action; Mining Permit; Grounds for Denial; Nonrenewal, Suspension, or Revocation of a Mining Permit.

(a) The State Fire Marshal shall investigate any alleged violation of Chapter 552, F.S., or this rule.

(b) The following acts constitute cause for disciplinary action:

1. Violation of any provision of Chapter 552, F.S., or any rule adopted pursuant thereto.

2. Violation of the ground vibration, frequency limits set forth in Section 552.30, F.S.

3. Failing to obtain, retain or maintain one or more of the qualifications for a mining permit as specified in this chapter.

4. Making a material misstatement, misrepresentation, or committing fraud in obtaining or attempting to obtain a mining permit.

5. Failing to maintain any record required pursuant to Chapter 552, F.S., and any rule or code adopted pursuant thereto.

6. Falsifying any record required to be maintained by Chapter 552, F.S., or rules adopted pursuant thereto.

(c) The lapse or suspension of a mining permit by operation of law or by order of the State Fire Marshal or a court or its voluntary surrender by a mining permit holder does not deprive the State Fire Marshal of jurisdiction to investigate or act in disciplinary proceedings against the mining permit holder.

(d) In addition, the State Fire Marshal shall not issue a new mining permit if it finds that the circumstance or circumstances for which the mining permit was previously revoked or suspended still exist or are likely to recur.

(12) Nothing in this rule shall impact a county's or municipality's authority to exercise whatever powers are not prohibited by Section 552.30, F.S.

(13)(a) Notwithstanding the standards in this rule, the Division shall, pursuant to Section 552.211(3), F.S., restrict the quantity and use of explosives at any location within the state when the Division determines, subject to protections provided by Chapter 120, F.S., the use of such explosives is likely to cause injury to life or property.

(b) Such restrictions shall be to the extent necessary to render the use of such explosives unlikely to cause injury to life or property.

(c) In determining that the use of explosives is likely to cause injury to life or property in a given location, the Division shall consider the following factors:

1. Distance of blasting activity to structures;

2. Use and occupancy of structures near blasting activity;

3. Geology of area near blasting activity; and

4. Type of construction use in structures near blasting activity.

5. Any credible evidence relevant to the risk of injury to life or property, not excluding evidence that existing damage resulted from causes other than the use of explosives.

(14) FLORIDA CONSTRUCTION MATERIALS MINING ACTIVITIES ADMINISTRATIVE RECOVERY ACT, SECTIONS 552.32-.44, FLORIDA STATUTES; BONDS, LETTERS OF CREDIT.

(a) Any person seeking to obtain a new User of Explosives License or to renew an existing User of Explosives License pursuant to the provisions of Section 552.091(5)(a), F.S., and who is engaged in or intends to engage in the use of explosives in connection with construction materials mining activities, or any person seeking to obtain a new Construction Materials Mining Permit or to renew an existing

Construction Materials Mining Permit issued pursuant to the provisions of Section 552.30, F.S., must post and maintain a bond, except as set forth in paragraph (d).

(b) Each bond shall:

1. Be issued by a surety company or by an insurance company licensed to issue surety bonds or to transact insurance in the State of Florida;

2. Contain as a condition of the undertaking the following statement in type at least as large as the size of the type for the remainder of the bond:

> THE CONDITIONS OF THIS OBLIGATION ARE SUCH THAT IF THE PRINCIPAL, the above bounded ______________________________________, shall faithfully comply with and conduct business under its license or permit in accordance with the provisions of the Chapter 552, F.S., and abide by all applicable statutes and rules and regulations of the Department of Financial Services (the Department) as promulgated by the Chief Financial Officer, the obligation shall be null and void; otherwise, it shall remain in full force and effect. This bond shall be in favor of the Department and shall specifically authorize recovery by the Department on behalf of a prevailing party in an action for damages sustained under the Florida Construction Materials Mining Activities Administrative Recovery Act, Sections 552.32-.44, F.S., in case the Principal is guilty of failing to pay damages awarded within 30 days after a final order is issued by an administrative law judge of the Division of Administrative Hearings, or within 30 days after the entry of an appellate mandate affirming a final order awarding damages.

3. Have attached to it a properly certified copy of the agent's Power of Attorney;

4. Be signed by the principal and have the signature of the principal witnessed;

5. Have typed below each signature the name of the person having affixed his or her signature;

6. Be countersigned by a Florida Resident General Lines Agent of the Surety which must not be a title insurer;

7. Be bound to the Department of Financial Services of the State of Florida or its successors in office, in the penal sum of $100,000.00 in the aggregate, lawful money of the United States of America, for payment of which well and truly to be made;

8. Provide for giving 30 days notice of cancellation in writing to the principal and filed with the Department of Financial Services by United States registered mail;

9. Contain at the top, centered, in not less than 14 point boldface type lettering the words, "Construction Materials Mining Company Bond, Section 552.38, F.S.".

(c) Although not required to be used, a form for a bond can be found at the Division of State Fire Marshal website located at http://www.fldfs.com/SFM/index.htm which, if used and properly completed, will comply in all respects with the requirements of this rule.

(d) In lieu of the bond required in paragraph (a), a person referred to in paragraph (a) is permitted to obtain and maintain a letter of credit, which for purposes of this subsection shall be referred to as "Letter." If a Letter is obtained and maintained in place of a bond, the following provisions apply.

1. Except as provided in this subsection, the provisions of Chapter 675, F.S., including, but not limited to, the definitions contained in Section 675.103, F.S., are applicable to each Letter, each party to a Letter, and to this subsection.

2. The issuer of the Letter must be a financial institution chartered under the laws of the United States of America or of the State of Florida.

3. The beneficiary of each Letter shall be the Department of Financial Services on behalf of a prevailing party in an action for damages sustained under the Florida Construction Materials Mining Activities Administrative Recovery Act, Sections 552.32-.44, F.S., if any person referred to in paragraph (a) fails to pay damages awarded within 30 days after a final order awarding damages is issued by an administrative law judge of the Division of Administrative Hearings, or within 30 days after the entry of an appellate mandate affirming a final order awarding damages.

4. The applicant for the Letter must be a person referred to in paragraph (a).

5.a. Each Letter must contain a condition of the undertaking.

b. The condition of the undertaking of each Letter is that the Letter shall specifically authorize recovery by the department on behalf of a prevailing party in an action for damages sustained under the Florida Construction Materials Mining Activities Administrative Recovery Act, Sections 552.32-.44, F.S., in the event that the applicant for the Letter fails to pay damages awarded within 30 days after a final order awarding damages is issued by an administrative law judge of the Division of Administrative Hearings, or within 30 days after entry of an appellate mandate affirming a final order awarding damages.

6. Each Letter must be authenticated by a signature which is on file with the department or in accordance with the standard practices referred to in Section 675.108(5), F.S.

7. The original of each Letter, once issued, must be maintained in the custody of the department.

8.a. No Letter is permitted to contain a statement that it is revocable.

b. If a Letter contains a statement that it is revocable, such Letter is void and of no effect for purposes of complying with the Florida Construction Materials Mining Activities Administrative Recovery Act, Sections 552.32-.44, F.S., or these rules.

9.a. Each Letter shall state that it is perpetual.

b. Each Letter shall be perpetual within the meaning of Section 675.106, F.S.

10.a. Each Letter must be replaced not later than 4 years and 6 months after the stated date of issuance or, if none is stated, after the actual date of issuance.

b. Failure to replace the Letter within the 4 years and 6 months period without providing a bond as permitted by paragraph (a) constitutes an immediate, serious danger to the public health, safety, and welfare, and shall result in an immediate final order of revocation of the licensee's or permittee's license or permit, and also constitutes grounds for the imposition of any other applicable penalty provided for in Chapter 552, F.S.

11.a. Each Letter shall be payable on or before the seventh day after presentation of a document evidencing satisfaction of the condition of the undertaking.

b. Presentation of a certified copy of a judgment awarding damages from an administrative law judge of the Division of Administrative Hearings under the Florida Construction Materials Mining Activities Administrative Recovery Act, Sections 552.32-.44, F.S., or a certified copy of an appellate court mandate affirming such a judgment, together with an affidavit from an authorized department representative that such judgment has not been paid, constitutes sufficient evidence to satisfy the condition of the undertaking for payment under the Letter.

c. Authorized representatives of the department are the Chief Financial Officer acting as the State Fire Marshal, the department's Chief of Staff, any Deputy Chief Financial Officer acting on behalf of the Chief Financial Officer acting as the State Fire Marshal, the director of the Division of State Fire Marshal, the Chief of the Bureau of Fire Prevention, the Safety Program Manager of the Bureau of Fire Prevention, and any attorney employed by the department.

d. Payment under the Letter shall be made to the "Department of Financial Services."

e. After receipt of payment of the Letter, the department shall deposit the check and, upon clearance of such check, the department shall issue a check for the exact same amount as the payment under the Letter to the owner or holder of the judgment referenced in this subsection.

12.a. Each Letter shall state that it is transferable and assignable from the department to the department's transferee or assignee.

b. The department's transferee or assignee shall be the owner and holder of a judgment from an administrative law judge of the Division of Administrative Hearings providing for damages under the Florida Construction Materials Mining Activities Administrative Recovery Act, Sections 552.32-.44, F.S., or a mandate affirming such a judgment, which the licensee or permittee has failed to pay within the time allotted in such Act.

13. Each Letter shall be governed by, and shall state that it is governed by, the laws of the State of Florida, regardless of the country, state, territory, or other location at which the Letter was applied for, requested, or issued.

14. Each Letter shall state that venue for any cause of action brought under the Letter in state court shall lie in the circuit court of the Second Judicial Circuit of Florida, in and for Leon County, and, if an action is brought under the laws of the United States of America, venue shall lie in the United States District Court for the Northern District of Florida, Tallahassee Division.

15. Each Letter is subject to approval by the department; however, if a Letter meets the criteria in, and complies with, subparagraphs 2. through 14. of paragraph (d) of this subsection, it shall be approved.

16. Once approved by the department, no Letter may be altered or amended in any manner except with

written approval of the department; however, any Letter which contains any alteration or amendment which meets the criteria in, and complies with, subparagraphs 2. through 15. of paragraph (d) of this subsection, shall be approved.

(e)1. Each bond or letter of credit shall provide security for payment of any award against the user or permit holder in the initial amount of not less than $100,000.00, which amount shall be maintained at all times the user or permit holder engages in construction materials mining activities. If the user or permit holder wishes, such bond or letter of credit may be maintained in an amount that exceeds $100,000.00.

2. If an award is made pursuant to Section 552.40(7), F.S., and the respondent which is a user or permit holder fails to pay the damages within 30 days after the final order is issued or within 30 days after the entry of an appellate mandate affirming a final order awarding damages, and the award is paid from the bond or letter of credit provided for in Section 552.38, F.S., and this rule, the respondent shall immediately secure a replacement bond or letter of credit in the full sum of not less than $100,000.00.

3. The respondent against whom the award was made and the award paid from the bond or letter of credit shall not engage in construction materials mining activities without having secured an effective replacement bond or letter of credit.

(f) Each person subject to Section 552.38, F.S., must complete and maintain on file with the Department of Financial Services form DFS-K3-1598, Rev. 6/04, which is hereby adopted and incorporated by reference. Form DFS-K3-1598 may be obtained by contacting the department at 200 East Gaines Street, Tallahassee, Florida 32399-0340, or by visiting the Division of State Fire Marshal website located at http://www.fldfs.com/SFM/index.htm.

(15)(a) Based upon the safe level of blasting vibrations for houses as shown in Figure B-1, United States Bureau of Mines, Report of Investigations 8507, notwithstanding the limits in subsection (4) above, the use of explosives within two miles of an urban development, as defined in paragraph (2)(e) above, shall not exceed a peak particle velocity of more than 0.5 inches per second due to the potential existence of plaster on lath construction.

(b) Measurement of such ground vibration levels shall be made consistent with subparagraph (4)(c)2. above at the nearest occupied residential structure within the urban development, which structure is not owned, leased, or contracted with the blasting or mining operation.

Rulemaking Authority 552.30, 552.38 FS. Law Implemented 552.20, 552.38 FS. History–New 11-25-01, Amended 6-24-02, Formerly 4A-2.024, Amended 10-27-04, 5-9-10.

Jacksonville COE			
Agency	**Contact**	**Sent E-mail/Called**	**Rcv'd Info**
Homeland Security-Civil Defense	westep@coj.net, 904-630-2472 or 904-334-9979	sent e-mail 11/9/2011	No
US Coast Guard	904-564-7500 or (904-564-7565)	left msg. w/ Mr. McDonnell	No
Jacksonville Fire Dept.	904-630-0434 or rembry@coj.net	sent e-mail 11/9/2011	No
Jacksonville Police Dept.	904-630-0500 or 904-630-2007	left msg.but also told me to call the ATF	No
ATF	904-830-5500 (Indust. Op.)	tried to leave msg., but mailbox was full	No
Florida Fire Marshall's Office	904-380-5500	called & left msg., also filled out "contact us" form online	Yes, from Carl Thompson (352-369-2845) EM-385-1-1 & Florida Statue 69A-2.024
Florida DEP	407-897-2931	left msg w/ Tracy Anger	Yes, Tracy called back and put me in touch w/Russell Simpson @ the N.E. division (904-256-1653), who put me in touch w/Marty Seeling (850-414-7728) at the Beaches & Shores staff who fw'd our e-mail to Mike Carothers (DEP) & Terri Jordan-Sellers (Corps), but have gotten no response.
Jacksonville Port Authority	800-874-8050	left msg., someone called back and told me to e-mail bonnie.burton@jaxport.com, I did 11/9/11	No

ATF CODE FEDERAL EXPLOSIVES LAWS AND REGULATIONS (2007)

These federal laws govern the manufacture, distribution, transportation and storage of explosives. All that handle explosives must go through a background check

COAST GUARD

The Port authority and Coast Guard will get answers for the question about the following:

- Any regulations on transportation of explosives to site
- Docks to be used for loading explosives on barges
- Explosives magazines on barges
- Special explosives containers
- Any special regulations on use of or transportation of explosives, special precautions,
- Limitations on land transport (routes)
- Safety zones Pilots associations Need for a police escort on land,
- Hours for moving explosives,
- Dames point bridge piers and vibration limits
- Utilities on land adjacent to channel or crossing channel Utility maps for gas and petroleum pipelines.

JACKSONVILLE PORT AUTHORITY

The Port authority and Coast Guard will get answers for the question about the following:

- Any regulations on transportation of explosives to site
- Docks to be used for loading explosives on barges
- Explosives magazines on barges
- Special explosives containers
- Any special regulations on use of or transportation of explosives, special precautions,
- Limitations on land transport (routes)
- Safety zones Pilots associations Need for a police escort on land,
- Hours for moving explosives,
- Dames point bridge piers and vibration limits
- Utilities on land adjacent to channel or crossing channel Utility maps for gas and petroleum pipelines.

APPENDIX 1

Blast Monitoring Program for the Kill Van Kull, Deepening Project

Reference; USACE July 2004, U.S. Army Corps of Engineers, Planning Division: POC Howard Ruben , New York District, 26 Federal Plaza, New York, New York 10278-0090

US Army Corps of Engineers
New York District

Blast Monitoring Program for the Kill Van Kull Deepening Project

July 2004

Prepared By: U.S. Army Corps of Engineers
Planning Division: POC Howard Ruben
New York District
26 Federal Plaza
New York, New York 10278-0090

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EXECUTIVE SUMMARY

This report presents the results of a monitoring program which examined the fish communities of the New York/New Jersey Harbor Complex (Harbor), the potential effects of blasting on the aquatic biota of the Harbor, and recorded water-borne pressures from confined blasts. The study was required by the State of New Jersey Department of Environmental Protection (DEP) for the issuance of a water quality certification pursuant to Section 401(b) of the Federal Clean Water Act to authorize the proposed Kill Van Kull (KVK) Deepening Project. The KVK Deepening Project is part of the New York and New Jersey Harbor Navigation Study, which was authorized by §435 of the Water Resources Development Act (WRDA) of 1996.

The monitoring program for the KVK deepening project was comprised of a detailed literature search, which provided the basis for establishing a list of fish species likely to occur in the KVK and seasonal patterns of use by those species; a literature review of available engineering and scientific papers concerning the impact of underwater blasting on fisheries resources; and, a study recording water-borne blast pressures from confined blasts conducted as part of the ongoing KVK Deepening Project. The Blast Monitoring Program for the KVK Deepening Project was prepared by the U.S. Army Corps of Engineers – New York District (USACE) with contributions from the St. Louis District.

The Kill Van Kull is a tidal strait, located on the north side of Staten Island. This strait connects Newark Bay (Bergen Point) to the Upper New York Bay (Constable Hook). The Kill Van Kull is approximately 5 mi long, approximately 0.5 mi wide, and ranges between 10 and 50 feet deep. Small shoals and shallow areas are located along both shores with one larger shallow area at Port Johnson, located about mid-way on the north side of the Kill. Both shores also have structures such as piers (active and former), wrecks, rocks, piles, and the Bayonne Bridge near the western terminus.

In order to characterize the fish communities of the New York/New Jersey Harbor Complex (Harbor), fisheries catch data were reviewed from sampling projects conducted in the Harbor from 1986 to 1999. During this time period, 11 projects were completed that reviewed species of fish occurring at different locations throughout the Harbor. Results of these studies indicated that a diverse fish community utilizes the Harbor, 96 fish species overall, 1 shark species, and 3 skate species were identified. Methods of collection included otter trawls, gill nets, beach seines, and impingement collections from water intakes at power plants. The studies showed that several fish species inhabit the Harbor year-round albeit in different life stages (i.e., larvae present while adults absent); these species include winter flounder, windowpane flounder, and striped bass. Other species are present only during a portion of the year; these species include blueback herring, American shad, summer flounder and bluefish.

The potential impacts of underwater blasting on aquatic biota were investigated through an extensive literature review. The results indicated that the primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, particularly the swim bladder. The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality. Water depth, substrate type, depth of the fish, and size and species of fish are also contributing factors.

In-situ blast pressure monitoring was conducted to record water-borne blast pressures from confined blasts. Data was collected from actual blasts to compare with open water blasts, which are unconfined and produce high peak pressures in the water. Pressure data was collected from confined blasts of varying intensities to calculate theoretical mortality radii for aquatic organisms.

The blasts were recorded using a trigger-source transducer. This recording method allowed monitoring to take place at a location removed from the immediate blasting area. The blast pressures recorded in the KVK were noted to be quite low. The St. Louis District has performed numerous studies on the waterborne energy from blasting, and stated that the blast pressures recorded during the KVK study were among the lowest levels of maximum pressure recording that they've taken. The validity of the data and collection methods was confirmed through the use of consistency tests and comparison with recordings from previous studies. Based on the results, the St. Louis District judged the KVK blast data to be of high quality. Other measures of impact, both impulse and energy flux density, were to be calculated from the pressure wave data. The complexity of the waveform and the high level of noise relative to the measured pressures did not allow evaluation of either impulse or energy flux density.

Predictions based on the data collected from this study indicate that impacts on the aquatic community may be diminished through the use of arrays configured with maximum charge weights located in the middle of lesser charge weights. The data also infer that the confined charges used in the KVK Blasting Program appear to have less of an impact on aquatic biota than would equivalent open water charges.

1.0 INTRODUCTION

The Kill Van Kull Deepening Project is part of the New York and New Jersey Harbor Navigation Study (Harbor Navigation Study). The Harbor Navigation Study (HNS) was authorized by §435 of the Water Resources Development Act (WRDA) of 1996. The object of the HNS was to determine the best manner in which to provide safe and efficient access to the various marine terminals within the Port of New York and New Jersey for deeper-draft vessels already within the world's commercial fleet, or whose introduction to the fleet was reasonably foreseeable (USACE 2004a).

The channel deepening was originally planned to be an incremental process. However, it was determined that significant project cost savings could be realized from consolidating implementation of the proposed deepening. Savings would result primarily through the avoidance of repeated mobilization and de-mobilization efforts in the same area, reduced repetition of drilling and blasting in the same area, and increased production rates (USACE 2004a). In addition, it was determined that short-term and long-term environmental impacts associated with unconsolidated implementation would apply to consolidated implementation as well; there would be no significant environmental impacts solely attributable to consolidated implementation (USACE 2004b).

As a result, the United States Army Corps of Engineers – New York District (USACE) prepared a Limited Reevaluation Report (LRR) to address the consolidation of separately authorized navigation improvement projects. Vertical consolidation was authorized in §202 of WRDA 2000. Specific to the Kill Van Kull (KVK) deepening, the LRR recommended excavation of KVK Contract Areas 4b and 5 should be undertaken with the implementation of the 50-foot Recommended Plan (USACE 2004a).

1.1 Study Purpose and Need

The LRR recommends the excavation of KVK Contract Areas 4b and 5 to the 50-foot Recommended Plan (with 2-foot overdredge) through vertical consolidation. This would require the use of explosives to facilitate removal of bedrock in portions of the channel. Through issuance of, the State of New Jersey required implementation of a monitoring program to evaluate the impact of underwater blasting activities on aquatic biota that reside in or utilize the area as nursery or as part of migratory routes as part of the special conditions of the State Water Quality Certificate (WQC) (Appendix A). This study examines the fish communities of the New York/New Jersey Harbor Complex (Harbor), the potential effects of blasting on aquatic biota of the Harbor, and records water-borne pressures from confined blasts. Figure 1.1.1 presents the KVK's location in relation to the Harbor and Figure 1.1.2 shows the study area location.

1.2 Study Process

The study was comprised of two major components: a literature search and a water-borne pressure monitoring program including extrapolation of potential impacts to fisheries resources.

The literature search consisted of two sub tasks:

a) A detailed literature search including information from recent (circa. 1975 – 2003) fisheries surveys within the vicinity of the project site. An emphasis was placed on the fisheries of the KVK and Newark Bay. The literature search included examination of NY and NJ State Environmental Agency Archives as well as those of the USACE and the National Marine Fisheries Service (NMFS). This review provided the basis for finalizing a list of species likely to be found in the KVK and the extent of the seasonal periods of concern. This review was compared to those species, which were captured during the monitoring phase of the study. Special consideration was given to migratory species as well as any State or Federally listed species. The report discusses the relative abundance of common species as well as the general likelihood of different species occurring in the project area.

b) A review of the available engineering and scientific papers concerning the impacts of underwater blasting on fisheries resources. This review focused on data collected for marine/estuarine environments with conditions and species relevant to the KVK project. Keevin and Hempen (1997) provided a review of the effects of blasting on aquatic organisms associated with various blasting methods. Equations were provided that were used to calculate the blast impact zone for aquatic organisms. The type and quantity of explosive, how the explosives are set, ignition method, and water depth are important factors in this calculation. These equations were modified to estimate the blast impact zone (mortality distance) for the species of concern in the KVK/NB.

The water-borne pressure monitoring program consisted of the following:

Mid-water pressures, impulse, and energy flux density were determined for four locations from each blast. Eight shots were initiated and monitored. In addition, two small, open-water shots were conducted and used to determine the difference (amplitude reduction, frequency shifts, and temporal variations) between open-water and confined shots. The results of this comparison were used to estimate the kill radius for typical shots based on existing fish mortality models.

The tasks completed before monitoring included: understanding the bathymetry, currents and fauna of the rock removal zone to be monitored; and, fabrication of the pressure monitor positioning system. The tasks completed before each monitored shot included: consideration of shot timing and spatial location relative to monitoring positions, given the shot and marine environment; determination of approximate monitoring calculations for each given monitored shot; deployment of monitoring array and associated buoys; timing the monitors' initiation of the shot. During and following each monitored shot the following occurred; recording the pressure waves; storing the monitoring records; removal or repositioning of the equipment for the next shot or monitoring completion; and, vessel use to reach the drilling/shooting barge and transit to the monitoring locations. Placement of the four pressure monitors required consideration of tide cycle and depth and duration lengths for each production and open-water shot.

2.0 FISH COMMUNITY OF NEW YORK/NEW JERSEY HARBOR COMPLEX

2.1 Introduction

Fisheries catch data were reviewed from sampling projects conducted in the New York/New Jersey Harbor complex from 1986 to 1999. During this time period, 11 projects were completed that reviewed species of fish occurring at different locations in the large and diverse New York/New Jersey Harbor complex. Eight of these studies were reviewed and summarized in the New York and New Jersey Harbor Navigation Study, Final Environmental Impact Study (NY/NJFEIS) in December 1999. Additional fish sampling programs included in this review are the aquatic program 316(b) reports for the Hudson Generating Station on the lower Hackensack River in November 1988, the Linden Generating Station on the northern Arthur Kill in October 1989, and the Hudson River Aquatic Environmental Study in September 1988. The studies are were conducted along the Hudson River on the west side of Manhattan, Upper New York Bay, Lower New York Harbor, Hackensack River, Newark Bay, Kill Van Kull, Arthur Kill, and Raritan Bay. The reports reviewed included the following:

New York/New Jersey Final Environmental Impact Statement:

- Lawler, Matusky & Skelly Engineers. 1993. Arthur Kill Impingement and Entrainment Report, September 1991 – September 1992. Report to Consolidated Edison Company of New York, Inc.

- Lawler, Matusky & Skelly Engineers. 1996. Newark Bay Biological Monitoring Program. April 1995 – March 1996. Report prepared for the Port Authority of New York/New Jersey.

- Louis Berger & Associates, Inc. 1992. Staten Island Bridges Program Environmental Report.

- National Marine Fisheries Service. Undated. Results of a Biological and Hydrological Characterization of Newark Bay, New Jersey, May 1993 - April 1994.

- U.S. Army Corps of Engineers. 1999. New York-New Jersey Harbor Navigation Study-Biological Monitoring Program. USACE–New York District.

- U.S. Coast Guard. 1995. Draft Environmental Impact Statement/Draft Section 4(f) Statement. Staten Island Bridges Program, Modernization and Capacity Enhancement Project.

- Wilk, S.J., R.A. Pikinowski, D.G. McMillan, and E.M. MacHaffie. 1998. Seasonal Distribution and Abundance of 26 Species of Fish and Megainvertebrates Collected in the Hudson-Raritan Estuary, January 1992 – December 1997. Northeast Fish. Science Center Reference Document 98-10. 145 p.

- Woodhead, P.M.J. 1991. Inventory and Assessment of Habitat and Fish Resources and Assessment of Information on Toxic Effects in the New York/New Jersey Harbor Estuary. New York/New Jersey Harbor Estuary Program. Marine Sciences Research Center, State University of New York, Stony Brook, New York.

Other Studies:

- New York City Public Development Corporation. 1988. Hudson River Center Site Aquatic Environmental Study. Prepared by EEA Inc., Garden City, New York.

• Public Service Electric and Gas Company. 1988. Hudson Generating Station Supplemental 316(b) Report. Prepared by EA Science and Technology, Middletown, New York.

• Public Service Electric and Gas Company. 1989. Linden Generating Station Supplemental 316(b) Report. Prepared by EA Science and Technology, Middletown, New York.

The purpose of this literature review was to prepare a report that lists the fish species most likely to utilize or occur in the Kill Van Kull (KVK) and determine seasonal patterns of use by those species. For the purpose of this report, the surveys are referred to by the areas that were sampled, except for the New York and New Jersey Navigation Study, Final Environmental Impact Study which is referred to as NY/NJ-FEIS.

2.2 Fish Community Diversity

Results of the studies reviewed show a diverse fish community occurring within the complex. Overall 96 fish species from 47 families, 1 shark species, and 3 skate species were identified as utilizing or occurring within the Harbor Complex. Table 2.2.1 lists the species caught in the Harbor Complex.

The data that are available include information from collections made with otter trawls in channel, shoal, and interpier areas; and with gill nets, beach seines, and cooling water intake impingement collections at power plants. The more marine areas, including Lower New York Harbor, Raritan Bay, the south part of the Arthur Kill, as well as the power plant impingement data, tend to contain the most diverse fish communities.

Alewife (*Alosa pseudoharengus*) and weakfish (*Cynoscion regalis*) were the only species captured in all 11 surveys reviewed.

Fish species that were captured in a majority of the surveys included American eel (*Anguilla rostrata*), blueback herring (*Alosa aestivalis*), Atlantic herring (*Clupea harengus*), American shad (*Alosa sapidissima*), bay anchovy (*Anchoa mitchilli*), Atlantic tomcod (*Microgadus tomcod*), striped bass (*Morone saxitilis*), red hake (*Urophycis chuss*), spotted hake (*U. regia*), northern pipefish (*Syngnathus fuscus*), striped searobin (*Prionotus evolanis*), grubby (*Myoxocephalus aenaeus*), white perch (*M. americana*), bluefish (*Pomatomus saltatrix*), spot (*Leiostomus xanthurus*), cunner (*Tautogolabrus adspersus*), butterfish (*Peprilus triacanthus*), and winter flounder (*Pleuronectes americanus*).

Additional species that were identified in the surveys included hickory shad (*A. mediocris*), Atlantic menhaden (*Brevoortia tyrannus*), gizzard shad (*Dorosoma cepedianum*), silver hake (*Merluccius bilinearis*), northern kingfish (*Menticirrhus saxatilis*), scup (*Stenotomus chrysops*), striped killifish (*Fundulus majalis*), Atlantic silverside (*Menidia menidia*), lined seahorse (*Hippocampus erectus*), northern searobin (*P. carolinus*), black sea bass (*Centropristis striata*), crevalle jack (*Caranx hippos*), Atlantic moonfish (*Selene setapinnis*), tautog (*Tautoga onitis*), summer flounder (*Paralichthys dentatus*), smallmouth flounder (*Etropus microstomus*), windowpane flounder (*Scopthalmus aquosus*), hogchoker (*Trinectes maculates*), mummichog (*Fundulus heteroclitus*), and northern puffer (*Sphoeroides maculatus*).

Other species of note include conger eel (*Conger oceanicus*), striped anchovy (*Anchoa hepsetus*), rainbow smelt (*Osmerus mordax*), white hake (*U. tenuis*), threespine stickleback (*Gasterosteus aculeatus*), striped mullet (*Mugil cephalus*), naked goby (*Gobiosoma bosc*), Atlantic mackerel.

Table 2.2.1
Fish Species Collected in the New York/New Jersey Harbor Complex During Various Studies from 1986 to 1999

Family/Common Name	Genus Species
Requiem Sharks/ Smooth dogfish [a]	*Mustelus canis*
Skates/Clearnose Skate [a]	*Raja eglanteria*
Little skate	*Raja erinacea*
Winter skate[a]	*Raja ocellata*
Sturgeons/Atlantic sturgeon [a]	*Acipenser oxyrzynus*
Freshwater Eels/ American Eel	*Anguilla rostrata*
Conger Eel/ Conger Eel	*Conger oceanicus*
Herrings/ Blueback herring	*Alosa aestivalis*
American Shad	*Alosa sapidissima*
Hickory Shad	*Alosa mediocris*
Alewife	*Alosa pseudoharengus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic herring	*Clupea harengus*
Gizzard shad	*Dorosoma cepedianum*
Anchovies/ Bay anchovy	*Anchoa mitchilli*
Striped anchovy	*Anchoa hepsetus*
Smelts/ Rainbow smelt	*Osmerus mordax*
Bullhead catfishes/ White catfish[a]	*Ictalurus catus*
Brown bullhead [a]	*Ictalurus nebulosus*
Lizardfishes/ Inshore lizardfish	*Synodus foetens*
Carps and Minnows/ Goldfish [a]	*Carassius auratus*
Cods/ Silver hake	*Merluccius bilinearis*
Atlantic tomcod	*Microgadus tomcod*
Red hake	*Urophysis chuss*
Spotted hake	*Urophycis regia*
White hake	*Urophycis tenuis*
Atlantic cod [a]	*Gadus morhua*
Fourbeard rockling [a]	*Enchelyopus cimbrius*
Pollock	*Pollachius virens*
Cusk-eels/ Fawn cusk-eel [a]	*Lepophidium cervinum*
Striped cusk-eel [a]	*Ophidion marginatum*
Toadfishes/Oyster toadfish	*Opsanus tau*
Goosefishes/ Goosefish	*Lophius americanus*
Needlefishes/ Atlantic needlefish [a]	*Strongylura marina*
Killifishes/ Mummichog	*Fundulus heteroclitus*
Striped killifish	*Fundulus majalis*
Banded killifish [a]	*Fundulus diaphanous*
Silversides/ Inland silverside	*Menidia beryllina*
Tidewater silverside	*Menidia peninsulae*
Atlantic silverside	*Menidia menidia*

Table 2.2.1 (cont'd)
Fish Species Collected in the New York/New Jersey Harbor Complex During Various Studies from 1986 to 1999

Family/Common Name	Genus Species
Sticklebacks/ Threespine stickleback	*Gasterosteus aculeatus*
Fourspine stickleback [(a)]	*Apeltes quadracus*
Trumpetfishes/ Bluespotted cornetfish	*Fistularia tabacaria*
Pipefishes/ Lined seahorse	*Hippocampus erectus*
Northern pipefish	*Syngnathus fuscus*
Searobins/ Northern searobin	*Prionotus carolinus*
Striped searobin	*Prionotus evolanis*
Sculpins/ Longhorn sculpins [(a)]	*Myoxocephalus octodecemspinosus*
Grubby	*Myoxocephalus aenaeus*
Temperate Basses/ White perch	*Morone americana*
Striped bass	*Morone saxatilis*
Sea Basses/ Black sea bass	*Centropristis striata*
Sunfishes/ Black crappie [(a)]	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Largemouth bass[(a)]	*Micropterus salmoides*
White crappie [(a)]	*Pomoxis annularis*
Pumpkinseed [(a)]	*Lepomis gibbosus*
Warmouth[(a)]	*Lepomis gulosus*
Bluefishes/ Bluefish	*Pomatomus saltatrix*
Jacks/ Cravalle jack	*Caranx hippos*
Rough scad [(a)]	*Trachurus lathami*
Lookdown	*Selene vomer*
Atlantic moonfish	*Selene setapinnis*
Blue runner [(a)]	*Caranx chryos*
Snappers/ Grey snapper	*Lutjanus griseus*
Porgies/ Scup	*Stenotomus chrysopos*
Drums/ Weakfish	*Cynoscion regalis*
Spot	*Leiostomus xanthurus*
Northern kingfish	*Menticirrhus saxatilis*
Silver perch [(a)]	*Bairdiella chryosura*
Atlantic croaker [(a)]	*Micropogon undulatas*
Butterflyfishes/ Spotfin butterflyfish [(a)]	*Chaetodon ocellatus*
Mullets/ Striped mullet	*Mugil cephalus*
White mullet [(a)]	*Mugil cerema*
Wrasses/ Tautog	*Tautoga onitis*
Cunner	*Tautogolabrus adspersus*
Gunnels/ Rock gunnel	*Pholis gunnellus*
Stargazers/ Northern stargazer	*Astroscopus gattatus*
Combtooth Blennies/ Feather blenny [(a)]	*Hypsoblennius hentz*
Sand Lances/ American sand lance	*Ammodytes americanus*
Gobies/ Naked goby	*Gobiosoma bosc*
Seaboard goby	*Gobiosoma ginsburgi*
([a]) Species caught in only 1 or 2 out of 11 sampling programs	

US Army Corps of Engineers
New York District

Table 2.2.1 (cont'd)
Fish Species Collected in the New York/New Jersey Harbor Complex During Various Studies from 1986 to 1999

Family/Common Name	Genus Species
Mackerels/ Spanish mackerels [(a)]	*Scomberomorus maculatus*
Chub mackerel [(a)]	*Scomber japonicus*
Atlantic mackerel	*Scomber scombrus*
Butterfishes/ Butterfish	*Peprilus triacanthus*
Lefteye Flounders/ Smallmouth flounder	*Etropus microstomus*
Summer Flounder	*Paralichthys dentatus*
Windowpane	*Scopthalmus aquosus*
Fourspot flounder	*Paralicthys oblongus*
Righteye Flounders/ American plaice [(a)]	*Hippoglossoides platessoides*
Winter Flounder	*Pleuronectes americanus*
Soles/ Hogchoker	*Trinectes maculates*
Blackcheek tonguefish [(a)]	*Symphurus plagiusa*
Leatherjackets/ Orangespotted fish [(a)]	*Cantherhines pullus*
Planehead filefish [(a)]	*Monacanthus hispidus*
Boxfisbes/ Scrawled cowfish [(a)]	*Lactophrys quadricornis*
Puffers/ Northern puffer	*Sphoeroides maculatus*
Striped burrfish	*Chilomycterus schoepfl*
Goatfishes/ Spotted goatfish [(a)]	*Pseudupeneus maculatus*
([a]) Species caught in only 1 or 2 out of 11 sampling programs	

(*Scomber scombrus*), fourspot flounder (*Paralicthys oblongus*), little skate (*Raja erinacea*), oyster toadfish (*Opsanus tau*), rock gunnel (*Pholis gunnellus*), and American sand lance (*Ammodytes americanus*). Table 2.2.2 lists the species most likely to be found in the KVK based on the year to year occurrence of the species in the complex, on the catch locations in the studies reviewed (e.g., Arthur Kill, Newark Bay, and upper New York Harbor), and the numbers caught each year.

A total of 38 species were caught in only 1 or 2 of the surveys and included freshwater species, incidentals to the area, and species that may not be efficiently captured with the gear used for those studies. These species are marked with a superscript (a) on Table 2.2.1.

Table 2.2.2
Fish Species Likely to be Caught in the Kill Van Kull Based on Collection in Adjacent Portions of the Harbor Complex

Common Name	Genus Species
Skates/ Little skate	*Raja erinacea*
Freshwater Eels/ American Eel	*Anguilla rostrata*
Conger Eels/ Conger Eel	*Conger oceanicus*
Herrings/ Blueback herring	*Alosa aestivalis*
American Shad	*Alosa sapidissima*
Hickory Shad	*Alosa mediocris*
Alewife	*Alosa pseudoharengus*
Atlantic menhaden	*Brevoortia tyrannus*

Table 2.2.2 (cont'd)
Fish Species Likely to be Caught in the Kill Van Kull Based on Collection in Adjacent Portions of the Harbor Complex

Common Name	Genus Species
Atlantic herring	*Clupea harengus*
Gizzard shad	*Dorosoma cepedianum*
Anchovies/ Bay anchovy	*Anchoa mitchilli*
Striped anchovy	*Anchoa hepsetus*
Smelts/ Rainbow smelt	*Osmerus mordax*
Lizardfishes/ Inshore lizardfish	*Synodus foetens*
Carps and Minnows/ Goldfish [a]	*Carassius auratus*
Cods/ Silver hake	*Merluccius bilinearis*
Atlantic tomcod	*Microgadus tomcod*
Red hake	*Urophysis chuss*
Spotted hake	*Urophycis regia*
Fourbeard rockling [a]	*Enchelyopus cimbrius*
Toadfishes/Oyster toadfish	*Opsanus tau*
Killifishes/ Mummichog	*Fundulus heteroclitus*
Striped killifish	*Fundulus majalis*
Silversides/ Atlantic silverside	*Menidia menidia*
Sticklebacks/ Threespine stickleback	*Gasterosteus aculeatus*
Pipefishes/ Northern pipefish	*Syngnathus fuscus*
Searobins/ Northern searobin	*Prionotus carolinus*
Striped searobin	*Prionotus evolanis*
Sculpins/ Grubby	*Myoxocephalus aenaeus*
Temperate Basses/ White perch	*Morone americana*
Striped bass	*Morone saxatilis*
Sea Basses/ Black sea bass	*Centropristis striata*
Bluefishes/ Bluefish	*Pomatomus saltatrix*
Jacks/ Cravalle jack	*Caranx hippos*
Lookdown	*Selene vomer*
Atlantic moonfish	*Selene setapinnis*
Porgies/ Scup	*Stenotomus chrysopos*
Drums/ Weakfish	*Cynoscion regalis*
Spot	*Leiostomus xanthurus*
Northern kingfish	*Menticirrhus saxatilis*
Mullets/ Striped mullet	*Mugil cephalus*
Wrasses/ Tautog	*Tautoga onitis*
Cunner	*Tautogolabrus adspersus*
Gunnels/ Rock gunnel	*Pholis gunnellus*
Sand Lances/ American sand lance	*Ammodytes americanus*
Gobies/ Naked goby	*Gobiosoma bosc*
Mackerels/ Atlantic mackerel	*Scomber scombrus*
Butterfishes/ Butterfish	*Peprilus triacanthus*
Lefteye Flounders/ Smallmouth flounder	*Etropus microstomus*
Summer Flounder	*Paralichthys dentatus*
Windowpane	*Scopthalmus aquosus*

Table 2.2.2 (cont'd)
Fish Species Likely to be Caught in the Kill Van Kull Based on Collection in Adjacent Portions of the Harbor Complex

Fourspot flounder	*Paralicthys oblongus*
Righteye Flounders/ Winter Flounder	*Pleuronectes americanus*
Soles/ Hogchoker	*Trinectes maculates*
Puffers/ Northern puffer	*Sphoeroides maculatus*

Species lists of Essential Fish Habitat (EFH) by management geographic coordinate square have been designated by the Mid-Atlantic Fisheries Management Council and the National Marine Fisheries Service. The two management squares that include the KVK, Newark Bay, and Arthur Kill were reviewed to identify the designated species and life stages for the study area. The two EFH management squares reviewed also include Atlantic Ocean waters within the Hudson River estuary affecting Staten Island from Port Richmond, New York on the north, east around to Great Kills South Harbor of Great Kills, New York, south of Bayonne, New York. The species for which EFH was designated in the KVK, Newark Bay, and Arthur Kill areas included:

- For eggs, larvae, juveniles, and adults—winter flounder, windowpane flounder, scup, king mackerel (*Scomberomorus cavalla*), Spanish mackerel (*S. maculatus*), and cobia (*Rachycentron canadum*)

- For eggs, larvae, juveniles—red hake

- For larvae, juveniles, and adults—Atlantic sea herring, Atlantic butterfish, and summer flounder

- For juveniles and adults—bluefish, Atlantic mackerel, and black sea bass

- For larvae and juveniles—dusky shark

- For larvae and adults—sandbar shark

- For eggs—sand tiger shark.

The king mackerel, cobia, dusky shark, sandbar shark, and sand tiger shark were not caught in any of the projects reviewed for this report.

2.3 Abundance and Seasonal Distribution

The number of species encountered during the year follows a similar pattern among surveys with lowest numbers caught in the winter, increases occurring in the spring, staying at higher numbers in the summer and fall, and then declining into winter. This pattern reflects the overall nature of the complex with the spring migration into and fall migration out of the area by juvenile and adult stages of many anadromous and marine fish species. The adults of anadromous species (e.g., striped bass, Atlantic tomcod, American shad, blueback herring, and alewife) migrate through the harbor area to upstream brackish and freshwater spawning areas in the spring and juveniles migrate downstream into and through the harbor in late summer and fall. Many marine species spawn offshore and juveniles utilize the estuary as nursery habitat (e.g., bluefish, weakfish, and

Atlantic menhaden) from late spring through early fall. Other species may spawn in various portions of the harbor complex (e.g., bay anchovy and winter flounder).

The species that dominated the catches in the Hackensack River during 1988 included killifish, Atlantic silverside, Atlantic tomcod, bay anchovy, and winter flounder. The bay anchovy and Atlantic tomcod were most abundant in the lower Hackensack River. Species of winter flounder, bluefish, weakfish, Atlantic menhaden, and hake were only collected in the lower Hackensack River. In those catches, 90 percent of the Atlantic tomcod, and all of the bluefish and weakfish, were young-of-the-year fish.

The species that dominated the catches in the Arthur Kill during 1988 included winter flounder, weakfish, spotted hake, spot, and Atlantic tomcod, accounting for over 90 percent of the catch in the otter trawls. The catch of bluefish and weakfish were primarily juvenile fish.

The species that dominated the catches in the Hudson River pier study from 1986 to 1988 were striped bass, white perch, winter flounder, and tomcod, accounting for over 90 percent of the trawl catch. Striped bass, bluefish, and Atlantic menhaden dominated the gill net catch.

The NY/NJ-FEIS channel trawl sampling collected bay anchovy, striped bass, and weakfish as the dominant species. For the shoal sampling, the dominant species were bay anchovy, striped bass, winter flounder, and Atlantic silverside.

2.3.1 Winter (January-March)

Impingement catches in the Hackensack River in 1988 had the highest catch for white perch (January), red hake (January), and threespine stickleback (February) during the winter. Atlantic silverside, alewife, Atlantic tomcod, and gizzard shad comprised a large portion of the catch. Otter trawl catches of winter flounder (January) and striped bass (February) were highest during the winter. Trawl catches of white perch, red hake, and grubby were also high.

Impingement catches in the Arthur Kill in the winter of 1988-1989 had the highest catch for Atlantic silverside, striped bass, and gizzard shad in January and threespine stickleback in March. January catches of spot, silver hake, Atlantic menhaden, bay anchovy, windowpane flounder, and grubby were also high. Otter trawls in the Arthur Kill had the highest catch totals for winter flounder (January and February), grubby, white perch, and striped bass (all in January) during the winter. High catches also occurred for windowpane flounder and red hake.

Otter trawl collections in winter along the Hudson pier areas had the highest catch over the year for striped bass in March which, along with white perch, comprised the majority of the catch. Winter flounder and tomcod were also present in the catch in relatively high numbers compared to the remainder of the year.

The NY/NJ-FEIS channel sampling results for Winter 1994 showed the highest catches over the year for striped bass and white perch in March and grubby and rainbow smelt in January. Gizzard shad and winter flounder in January were also collected at that time. Trawl catches in 1996 only had winter flounder, striped bass, and gizzard shad. Trawl catches in 1999 showed the highest catches over the year for white perch, winter flounder, and striped bass in March.

The NY/NJ-FEIS shoal station catches for Winter 1994 had relatively few species and with low abundance. In 1996, the results showed the highest catches over the year for grubby in January. January catches of striped bass and winter flounder comprised the majority of the catch. The shoal catch results for Winter 1999 showed the highest catches over the year for Atlantic silverside in January and February, and for winter flounder and Atlantic herring in March.

2.3.2 Spring (April-June)

Impingement samples in the Hackensack River had the highest catch for blueback herring and summer flounder (May), and Atlantic menhaden, striped bass, and bay anchovy (all in June) during spring. Otter trawl catches were highest for the year for Atlantic tomcod (June) and American shad (May). Trawl catches of red hake and hogchoker were also made.

Impingement sampling in the Arthur Kill during the spring had the highest catch for the year for spotted hake (April). Higher catches of Atlantic silverside, Atlantic menhaden, and blueback herring were also made. Otter trawls in the Arthur Kill had the highest catch totals of the year for spotted hake in May and showed high catch totals for April through June. The winter flounder, grubby, red hake, and Atlantic tomcod all had relatively high catch totals. Spring beach seine collections in the Arthur Kill had the highest catch for the year for bay anchovy in June and Atlantic tomcod and northern pipefish in May. Atlantic silverside, striped bass, and winter flounder comprised the majority of the seine catch.

Otter trawl collections in Spring 1986 along the Hudson River pier areas had the highest catch over the year for Atlantic tomcod, American shad, summer flounder, hogchoker, and American eel in May. Winter flounder and striped bass were also present in the catch in high numbers in April while Atlantic silverside catches in May and June are high. Otter trawl collections in Spring 1987 had the highest catch over the year for Atlantic tomcod and alewife in May; summer flounder, striped bass, white perch, and winter flounder in May; and Atlantic silverside in June. The spring gill net collections had striped bass, Atlantic menhaden, and bluefish comprising the majority of the catch. The highest gill net catches for the year were recorded for striped bass and bluefish during spring.

The NY/NJ-FEIS channel sampling results for Spring of 1993 showed the highest catches over the year for spotted hake in June. Spotted hake was also high in the May catch. Atlantic tomcod, striped bass, grubby summer, and winter flounder were all caught in higher numbers. Trawl catches in 1995 showed the highest catches over the year for spotted hake in May and winter flounder in June. Trawl catches in 1999 showed the highest catches over the year for spotted hake and windowpane flounder in April and Atlantic tomcod in June. Winter flounder and striped bass comprised the majority of the catch in April. Winter flounder and bay anchovy comprised the majority of the catch in June.

The NY/NJ-FEIS shoal station catches for Spring 1993 showed the highest catches over the year for Atlantic herring, Atlantic tomcod, and winter flounder in June. Bay anchovy and striped bass were also present in catches. In 1995, the results showed the highest catches over the year for striped bass in April and May. Winter flounder, bay anchovy, summer flounder, and spotted hake were caught in increased numbers. The shoal sampling for Spring 1999 showed that catches of striped bass, Atlantic tomcod, bay anchovy, alewife, blueback herring, and winter flounder comprised the majority of the catch.

2.3.3 Summer (July-September)

Impingement samples in the Hackensack River had the highest catch for Atlantic tomcod, bluefish, and Atlantic silverside for the year in September. Catches of Atlantic menhaden, weakfish, winter flounder, and blueback herring all occurred at that time. Otter trawl catches were highest for the year for alewife, bluefish, and Atlantic menhaden in August and weakfish in September. Winter flounder and striped bass were also caught in each month.

Impingement samples in the Arthur Kill in the summer had the highest catch for the year for bluefish and Atlantic menhaden in July and for bay anchovy in September. Blueback herring catches were high in July, then declined into September. Otter trawls in the Arthur Kill had the highest catch totals of the year for weakfish, Atlantic tomcod, spot, bay anchovy, striped searobin, and windowpane flounder in September. Catches of spotted hake and grubby decreased into September. Summer beach seine collections in the Arthur Kill had the highest catch for the year for Atlantic silverside and bluefish in August and in September. Bay anchovy catches in July were almost at the highest and then no catch was recorded in August and September. Atlantic silverside, striped bass, and winter flounder comprised the majority of the seine catch.

Otter trawl collections in Summer 1986 along the Hudson River pier areas had the highest catch over the year for Atlantic silverside in July. Catches of the silverside remained high into September. Bluefish, summer flounder, winter flounder, and hogchoker were also present in the catch. Otter trawl collections in Summer 1987 had high catches of striped bass and Atlantic silverside. The summer gill net collections had the highest catch for Atlantic menhaden for the year. Striped bass and bluefish comprised the majority of the summer catch.

The NY/NJ-FEIS channel sampling results for Summer 1993 showed the highest catches over the year for Atlantic tomcod, bay anchovy, summer flounder, and Atlantic menhaden in July and weakfish in September. High catches of striped bass in July and winter flounder were made in August. Trawl catches in Summer 1995 showed the highest catches over the year for Atlantic tomcod in July and bay anchovy in August. Catches of grubby and winter flounder were high in July but decreased in to September. Trawl sampling in 1999 showed the highest catches over the year for weakfish, Atlantic silverside, and alewife in July. High catches of bay anchovy, scup, and butterfish were also noted in summer.

The NY/NJ-FEIS shoal station in 1993 showed the highest catches over the year for summer flounder in July and bay anchovy and bluefish in September. Striped bass catch totals were also high. In 1995, the results showed the highest catches over the year for bay anchovy, Atlantic silverside, bluefish, American shad, winter flounder, white perch, and northern kingfish in September; weakfish in July; and summer flounder in August. In 1999, the results showed the highest catches over the year for weakfish in July and bay anchovy in September. Striped bass had higher catch totals in July and decreased into September.

2.3.4 Fall (October-December)

Impingement samples in the Hackensack River had the highest catch for the year for Atlantic silverside, weakfish, and Atlantic herring in October; alewife, American shad, and gizzard shad in November; and white perch in December. Catches of Atlantic menhaden, bluefish, blueback herring, and Atlantic tomcod were high. Catches of bay anchovy and Atlantic silverside decreased into December. Otter trawl catches were highest for the year for American eel in October and blueback herring and white perch in December. Catches of Atlantic tomcod dominated the totals for all three months.

Impingement samples in the Arthur Kill in Fall 1988 had the highest catch for the year for weakfish in October; blueback herring, American shad, and silver hake in November; and spot and alewife in December. Gizzard shad and Atlantic silverside numbers increased in catch totals from October to December. Otter trawls in the Arthur Kill had the highest catch totals of the year for red hake in November. Winter flounder and Atlantic tomcod have high catch rates, however, tomcod numbers decrease into December. October beach seine collections in the Arthur Kill had Atlantic silverside and bluefish comprising the majority of the catch.

Otter trawl collections in Fall 1986 along the Hudson River pier areas had the highest catch over the year for alewife and white perch in November and winter flounder in December. Catches of striped bass increased to another high point in December for the year. Otter trawl collections in Fall 1987 were low with striped bass, Atlantic tomcod, and winter flounder in the catch. The fall gill net collections had low abundance with Atlantic menhaden, bluefish, and striped bass accounting for the majority of the catch.

The NY/NJ-FEIS channel sampling results for Fall 1993 showed the highest catches over the year for alewife, gizzard shad, and winter flounder in November. High catches of striped bass, white perch, and Atlantic tomcod were evident. Weakfish was abundant in the October catch, then decreased into December. Spotted hake appeared in samples in high numbers from October to December. Trawl sampling in Fall 1995 showed the highest catches over the year for striped bass in December. The grubby and Atlantic tomcod were caught again in December. Weakfish were only caught in October. Trawl catches in Fall 1998 showed the highest catches over the year for bay anchovy in October and American shad in November. Weakfish was abundant in October, and then the catch decreased.

In 1993, the NY/NJ-FEIS shoal station showed the highest catches over the year for striped bass and Atlantic silverside in October. In 1995, the results showed high catches for bay anchovy, Atlantic silverside, and striped bass in October with catches decreasing into December. In 1998, the results showed the highest catches over the year for striped bass in November. Winter flounder, black sea bass, bay anchovy, Atlantic silverside, and smallmouth flounder comprised the majority of the catches.

2.4 Summary

The results show that several fish species are found in the complex for most of the year and most probably would occur in the KVK. These species are present not necessarily at all life stages throughout the year, but may occur during a certain life stage at different times of the year. These species include the anadromous species striped bass and Atlantic tomcod, and also white perch, winter flounder, windowpane flounder, and grubby.

The catch results also show several fish species that spend part of the year in the complex and could be found in the KVK during that time. These species included the anadromous species of blueback herring and American shad, and also weakfish, Atlantic herring, Atlantic menhaden, rainbow smelt, Atlantic silverside, bay anchovy, summer flounder, red hake, spotted hake, and bluefish.

The fish species that dominated the collections included striped bass, white perch, winter flounder, Atlantic tomcod, spotted hake, bay anchovy, Atlantic silverside, Atlantic menhaden, bluefish, spot, and weakfish. Table 2.4.1 lists the dominant species and summarizes probable occurrence during the year based on the sampling data.

Table 2.4.1
Seasonal Occurrence of Dominant Fish Species in the New York/New Jersey Harbor Complex in Sampling Programs from 1986 to 1999

Common Name	Primary Occurrence in Catches During the Year	High Level Months	Peak Months
Striped bass	All year Gill Net – May and June	Nov – March	Jan – March
White perch	Oct – June	Nov – March	Jan – March
Winter flounder	All Year	Nov – June	Nov – March
Atlantic tomcod	All Year	Apr – Dec	Apr – Aug
Spotted hake	Apr – Jul and Oct – Dec	May – June	May – June
Bay anchovy	June – Dec	June – July	July
Weakfish	May – Dec	Aug – Nov	Aug – Oct
Atlantic menhaden	May – Dec	June – Sept	July – Aug
Bluefish	June – Oct	July – Sept	July
Atlantic silverside [a]	May – Dec	June – Sept	July – Aug
([a]) Collected primarily in shoal areas			

3.0 POTENTIAL EFFECTS OF BLASTING ON AQUATIC BIOTA OF THE NY/NJ HARBOR COMPLEX

3.1 Introduction

This section summarizes scientific information compiled to determine the potential impacts of underwater blasting on aquatic biota of the Kill Van Kull (KVK).

Keevin and Hempen (1997) presented an extensive review of information describing those characteristics of underwater explosions and the associated processes that impact aquatic biota. Much of the information presented here is selectively abstracted from their work, targeting conditions, to the extent possible, representative of the blasting procedures implemented in the Kill Van Kull (KVK) federal navigation channel improvement project.

The KVK navigation channel improvement project requires blasting to fracture and remove bedrock in order to achieve the target project depth of 50-ft below mean low water plus a 2-feet overdredge. The blasting process entails the use of barge-mounted drill towers to bore a series of holes into the bedrock. Typically, the 4.5-in. diameter holes are 10- to 15-feet deep into bedrock, and arranged approximately 12 feet apart in a row configuration referred to as a range. Each range typically consists of 6 holes in a line. Each blast event (shot) may have up to 5 parallel ranges separated by 10 feet with boreholes staggered between adjacent ranges. The arrangement of holes can vary among shots, depending on factors such as location, thickness of rock to be removed, and specific objective of the shot. Each hole is packed with water gel ammonium nitrate derivative high explosive, and stemmed with coarse gravel at the top of the hole to confine and direct the blast energy into the rock. A detonation cord runs from the barge to a booster at each hole. Delays are used for detonation of each shot, i.e., the charges in individual holes are detonated in sequence with a detonation delay of 25 m-seconds between holes.

3.2 Relevant Underwater Blast Shock Wave Characteristics

For detonations in rock such as the KVK channel deepening project, the most important factors in accomplishing the work of fracturing and displacing rock in close proximity (3-10 diameters of the explosives volume) to the explosives material are thermal and high pressure detonation effects (Keevin and Hempen 1997). However, these effects have negligible impacts on aquatic organisms. Beyond this point in the far-field area, the primary source of damage to aquatic organisms is the shock wave.

The nature of the shock created by use of underwater explosives and physical factors that can affect fish survival is the composite result of multiple pressure wave components including the direct wave, air-water surface-reflected wave, bottom-reflected wave, and bottom-transmitted wave (McPherson 1991). The location of the explosive (e.g., mid-water, placement in bedrock) and method of detonation (e.g., single charge, multiple charges with delays) will affect these component waves that are the predominant factors that influence the character of the composite shock wave (Figure 3.2.1). The direct shock wave results in the peak shock pressure or compression and the reflected wave at the air-water surface produces negative pressure or expansion. For confined underwater explosives, these are the primary wave components responsible for injury to aquatic organisms (Wright and Hopky 1998; Keevin and Hempen 1997; Linton et al. 1985; Wiley et al. 1981).

One feature of blasting in aquatic environments is the "cavitation hat," related to the reflected wave in proximity to the air-water surface. The negative reflected wave generated by the deflection of the water surface toward the air results in a shallow disc of negative pressure centered over the explosive. There is high potential for overextension of air filled organs in aquatic biota due to the negative pressure associated with the cavitation hat.

The direct or primary shock wave (P-wave) in the far-field area is an expanding compression wave, marked by a rapid, nearly instantaneous increase to peak pressure (P_m) as it passes a given point at distance from the explosion followed by an exponential decline in pressure (Figure 3.2.1) to ambient hydrostatic pressure. The surface-reflected wave trails the direct wave and is characterized by a rapid decrease in pressure to below ambient followed by an exponential increase to ambient hydrostatic pressure. The resultant effect experienced by an aquatic organism in the path of this wave is a rapid sequence of compression and expansion (oscillation) over a period of microseconds depending on the distance from the detonation.

Three characteristics of the composite pressure wave generated from a detonation have been used to assess the impact of blasting on aquatic biota and predict safe ranges from detonation sites: P_m, impulse (I), and energy flux (E_f). P_m is a function of the weight (W in kg) of the explosive and the distance (r in meters) from the explosive:

$$P_m = 53.1 \text{ x } R_s^{\ -1.13}$$

where Rs is defined as the scaled range,

$$R_s = r \ / \ W^{\ 1/3}$$

The equation to calculate R_s provides a means to scale the effects of blasting for different weights of explosive at a selected distance from the detonation (Linton et al. 1985). That is, P_m is proportional to the cube root of the weight of the explosive (W).

Impulse is a measure of the strength or momentum of the pressure wave as it passes a surface. The impulse is a function of the pressure (psi) and the time over which the pressure is produced (Linton et al. 1985). It is calculated as the integral of the area under the pressure-time curve. Depending on their purpose, various authors have included either or both the positive and negative portions of the pressure-time curve in this calculation (Keevin and Hempen 1997). The severity of injury to fish is generally reported to be proportional to the magnitude of the impulse produced by the explosive (Linton et al. 1985).

Energy flux density is a measure of the intensity of the shock wave or the change in energy across a surface in the path of the shock wave. It is measured in units of energy per unit area (e.g., joules/m^2). The integral of E_f can be approximated in terms of W and R_s (Keevin and Hempen 1997). The shock wave energy is also affected by the detonation velocity of the selected explosive; higher velocity explosives generate greater energy. For example, water gel explosives as used for the KVK project generate less shock energy than dynamite.

The KVK blasting protocol has attempted to optimize production and reduce the environmental effects as defined by Keevin and Hempen (1997). Optimized blasting (Keevin and Hempen 1997) is accomplished by:

- Reducing the weight of explosive by accounting for the characteristics of the media, blasting pattern, and the properties of the blasting material

- Use of water gel explosives

- Increasing the number of delays to progressively displace material

- Stemming boreholes to prevent pre-mature venting of explosive gases and dampen the pressure shock wave.

3.3 Blast Impacts on Aquatic Organisms

The primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, in particular the swimbladder (Wright and Hopky 1998; Keevin and Hempem 1997). The gas-filled swimbladder is a structure possessed by many pelagic fish that plays a role in buoyancy. Demersal species, such as flounder, typically do not have swimbladders and are frequently less susceptible to blast impacts. Less information is available, but it is generally reported that there is minimal injury and mortality from blasting to mollusks, shellfish, and crustaceans which do not have gas-filled organs similar to the swimbladder in fish (Wright and Hopky 1998). Although the structure of the swimbladder and the mechanism for adjusting gas volume vary among species, generally the process for release of gas from the swimbladder is too slow to compensate for the rapid fluctuations in hydrostatic pressure associated with the pressure shock wave.

The primary cause of damage in finfish exposed to a pressure shock wave appears to be the outward rupture of the swimbladder as a result of the expansive effect of the negative hydrostatic pressure associated with the reflected air-water surface wave. While the organ may tolerate the compressive portion of the shock wave, the rapid drop to negative hydrostatic gage pressure and expansion of the gas that cannot otherwise be released, causes the rupture of the organ (see photo, below). Vibration, expansion, and rupture of the swimbladder can also cause secondary damage and hemorrhage due to impact with other internal organs in close proximity to the swimbladder. Other organs typically exhibiting damage include the kidney, liver, spleen, and sinus venous. Extensive tearing of tissue has been observed in species where the swimbladder is closely attached to the visceral cavity. Close attachment to the dorsal cavity wall was typically associated with extensive damage to the kidney. Species with thick-walled swimbladders and cylindrical body shape (e.g., oyster toad fish and catfish) appear to be more resistant to pressure waves than species with laterally compressed bodies such as herring and menhaden (Linton et al. 1985). Smaller individuals of a species are generally more sensitive than larger fish. Early larvae do not have swimbladders and are more resistant than older larvae after development of the swimbladder. The extent of injury and mortality decreases with distance from the detonation as the magnitude of the pressure drop declines due to dissipation of the blast impulse (I) and energy flux density (E_f) with distance. In a review of a number of studies of primarily open water blasting, Keevin and Hempen (1997) concluded that I was the best predictor of potential damage for shallow depths (less than 3 m), while E_f was the best predictor for deeper conditions.

The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality, although water depth, substrate, depth of the fish, and size and species of fish are also important (Keevin and Hempen 1997; Wiley et al. 1981; Teleki and Chamberlain 1978). The shape of the lethal zone is dependent on the depth of the detonation. In shallow water, the horizontal extent is greater than in deep water. However, for buried explosives, the lethal zone is conical with the narrow portion of the lethal zone near the bottom expanding horizontally toward the water surface (Linton et al. 1985).

Dissection of Striped Bass (Morone saxatilis), recovered after blast, illustrating rupturing of swim bladder.

Several authors have developed empirical models to integrate these factors in order to predict impacts to aquatic organisms; however, most of these are based on open water detonations and thus, overestimate the lethal range and impact to fish compared to blasting with explosives buried in the substrate as is the case for the Kill Van Kull project. Keevin and Hempen (1997) reviewed several of these models. A set of computer models was developed by Coastline Environmental Services (1986) that can provide rough approximations of the potential lethal radius for open water and buried borehole blasts based on *I* (IBLAST) for shallow water and *Ef* (EBLAST) for deep water sites.

The Canada Department of Fisheries and Oceans evaluated P_m, I, and E_f as predictive parameters for establishing guidelines for protection of fish and marine mammals during use of explosives in Canadian waters (Wright 1982) and found an impulse-based model to be the best predictor of lethal and safe ranges. Wright found that overpressure greater than 100 kilo Pascals (kPa) (14.5 psi) generally caused internal organ damage in finfish. This 100 kPa threshold has been used a guideline to limit blasting impacts in Canadian waters (Wright and Hopky 1998). However, based on reviews of several studies, Wright (1982) reported that P_m is affected by an array of factors, including size and species of fish, orientation of fish relative to the direction of the pressure wave, target depth, detonation depth, water depth, bottom type, and explosive type and quantity and thus, was a poor predictor of lethal range. Predictive equations (MacLennan 1977) for lethal range based on E_f were inconsistent in their ability to predict lethal ranges under different test conditions (Hill 1978; Roguski and Nagata 1970; Hubbs et al. 1960; Tyler 1960). Field tests (Yelverton et al. 1975) indicated that the lethal impulse values were relatively consistent for various test conditions, but peak lethal pressures varied widely. In a series of tests with bluegill and carp, Wright reported that while peak pressure remained constant with depth at test locations, the impulse and mortality increased with depth. Wright presents a procedure (based on Hill 1978) to calculate the lethal range based on scaled impulse (I_{sc}) (calculated from an impulse value determined to e protective of fish) and R_s that also considers fish size, fish depth, charge size, and detonation depth. Scaled impulse is calculated as;

$$I_{sc} = I / W^{1/3}$$

and compared to R_s using a series of curves that relate W, the depth of the charge (D_c), and depth of the fish (D_f):

$$A = (D_f \times D_c) / W^{2/3}$$

The lethal range (R_m) is calculated from R_s selected based on the ratio, A and the calculated I_{sc}:

$$R_m = R_{sc} \times W^{1/3}$$

Wright concludes that the method will underestimate R_m in shallow water if the water depth is less than 5 times the detonation or fish depth or for rocky bottoms. On the other hand, Wright's procedure is based on field data secured from open water blasts and will overestimate R_m relative to situations where the explosive is placed in stemmed boreholes. In reviewing Wright (1982) and Hill (1978), Keevin and Hempen (1997) indicate that a more precise model would do little to improve the accuracy of the predicted lethal zone, considering the number of conditions that affect mortality, but are difficult to quantify. Examples of information that can generally only be assumed at the time of a blast include: size distribution of fish, depth and horizontal distribution of fish, and fish community structure. Keevin and Hempen indicate that a conservative estimate of potential mortality is provided by the using the model to assess "worst case" potential impact.

Young (1991) presented a model to estimate the range of vulnerability using 90 percent probability of survival as the threshold criteria. This model was generated for shallow water conditions and open water blasts. Because the model is based on a limited range of conditions, Young characterized it as useful for preliminary planning purposes:

$$R_{safe} = 95 \times W_f^{-0.13} W^{0.28} d_w^{0.22}$$

where

R_{safe} = Safe range (ft)
W = Weight of explosive (lb)
W_f = Weight of fish (lb)
D_w = Depth of detonation (ft).

Wiley et al. (1981) developed a dynamic model to simulate the effect of the passage of a pressure shock wave on the oscillatory vibration of a generic swimbladder (Figure 3.3.1); modeled estimates of swimbladder motion (oscillation parameter Z) were correlated with severity of observed injury to fish in caged studies with open water blasts. They present a method for calculation of the probable distribution of mortality as a function of horizontal range and depth. The authors found good agreement between their oscillation damage parameter and the impulse damage parameter developed by Yelverton et al. (1975). It is suggested that this similarity occurs because the oscillatory motion described by their model is a result of the impulse pressure loading on the swimbladder air volume. The model and relationships between characteristics of the pressure wave and severity of injury observed by Wiley et al. were consistent only for detonations in shallow water. Using an average relationship between fish length and swimbladder radius for striped bass, Wiley et al. calculated estimated kill zones (90, 50, and 10 percent) for striped bass, shown on Figure 3.3.2. The authors also presented estimates of variation in mortality as a function of both depth and fish size (Figure 3.3.3). Field tests were performed where water depth was 46 m to minimize the affects of reflected bottom pressure waves; 14 of 15 blasts monitored were detonated at a depth less than approximately 12 m. The testing program looked at a number of species that may be seasonally abundant in the New York/New Jersey Harbor complex including white perch (*Morone Americana*), spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*), blueback herring (*Alosa aestivalis*), hogchoker (*Trinectes maculates*), toadfish (*Opsanus tau*), and killifish (*Fundulus majalis*). Hogchokers, a species with no swimbladder, were reported to sustain no serious injury. Wiley et al. reported that the damaged swimbladder of some species, such as white perch and spot, healed in as little as 10 days under laboratory conditions, but that the organ was less effective in controlling internal hydrostatic pressure and buoyancy.

The U.S. Army Corps of Engineers – Wilmington District (2000) examined the results of test blasting in Wilmington Harbor/Cape Fear River used to evaluate the model predicted impact zone and the effectiveness of impact reduction using an air bubble screen. This report found that field tests with caged fish demonstrated that the impact modeling conducted for the Environmental Impact Statement on this project significantly overestimated the horizontal extent of fish mortality. The model-predicted impact area (USACE 1996a, 1996b), defined as that area in which 1 percent or more of the fish would die without an air curtain, extended to 656 ft from the blast (34.5 acres). In field test, no significant mortality occurred beyond 140 ft (2.1 acres within 140 ft) with or without the air curtain. The U.S. Army Corps of Engineers – Wilmington District (2000) suggested that the reason for the significant overestimate by the model was that the Environmental Impact Statement model underestimated the reduction in blast effects compared to open water by confining the explosive in rock. The test blasts consisted of 32 to 33 holes with 52 to 62 pounds of explosive per hole with 25 microsecond delays; water depths were 30 to 38 feet. The Waterways Experiment Station found that the effect of a rock blast is 0.014 of a blast in open water; this translates to an equivalence of a 52 to 62 pound blast in rock to a 0.73 to 0.87 pound blast in open water. The reported average P_m and average peak I from the test rock blasting at the 140-ft radius were 75.6 psi and 18.4 psi-msec, respectively; it was reported that these values were similar to impact threshold values estimated by Yelverton et al. (1975). It was suggested that the ineffectiveness of the air curtain was a result of the strong tidal currents in the Cape Fear River that disrupted the air curtain and the establishment of an effective air barrier.

4.0 WATER-BORNE PRESSURES FROM CONFINED BLASTS IN THE KVK

4.1 Introduction

The purpose of the study was to record water-borne blast pressures from confined blasts conducted in the Kill Van Kull and relate them to impacts to resident fishery resources. The blasting was part of the ongoing Kill Van Kull (KVK) Deepening Project. The blasting was confined within the rock floor of the KVK to remove rock for channel deepening. The United States Army Corps of Engineers - New York District funded the study in an effort to record data from actual confined blasts. These data were then compared to data recorded from open-water blasts, which are unconfined and produce higher peak pressures in the water column. The pressure data was recorded to measure the various typical pressures associated with impacts to aquatic and marine organisms. The blast monitoring was conducted during the last two weeks of October 2003.

The formulas and computational methodologies used to develop the information contained in the following chapter are highly technical and have thus been included in an expanded version of this chapter included as Appendix A.

4.2 Materials and Methods

A. Channel Deepening Blasting

Figure 4.2.1 provides the approximate location of the shooting in October 2003 near the Bayonne Bridge at Bergen Point. Acceptance Areas A and B, east of the bridge, were the locations of the removal program. Figure 4.2.2 provides a typical section for channel depth and rock removal.

1. Types of Explosives and Initiation

The main blasting agent used in October 2003 by the Joint Venture was EL957C, a water gel emulsion, manufactured by ETI Canada Ltd. The emulsion is not cap sensitive. The emulsion has a specific gravity of 1.30 and a detonation velocity of 20,000 feet/second (fps). The blasting agent was packaged in 2.75-inch (in) diameter polythene sleeves, each weighing 4.23 pounds (lb). Typically charges ranged between 25 and 29 lb per shot hole, depending on the height of rock relative to the dredge depth of 53.5 feet (ft). Larger emulsion weights were often used in one or more holes for each shot.

The initiation system was comprised of a Detaline dual path, precision delay, **non-electric** initiation cord and components. By using a non-electric initiating system the shot was safely initiated and connected without concern for radio silence. Radios can initiate electric systems. The system utilizes a fine extruded detonating cord with a PETN explosive core of 2.4 grains per ft. The timing and delay sequence to the shot holes were achieved with "Detaslide Delays" detonators. The detonators were used in each booster and were connected via Detaline to "Detaline Surface Delays." The surface delays were connected to a dual trunk of Detaline.

All the shot holes were drilled, loaded and connected to the dual trunk line. The shot was initiated using a "Noiseless Lead-in-Line." An instantaneous detonator was attached to a 500-ft length of hollow shock tube that contained explosive dust. The entire shot was initiated by a simple shot-shell primer, which was fired into the shock tube connected to the trunk line delay system to the individual shot holes.

Upon initiating the blast, each cord carries the detonation to its shot hole. In doing so, the cord itself sets up a "tubular" pressure front that forms around the cord along its entire length. How the pressure from the multitude of Detalines affected the recorded blast pressures or how the lines may impact fish (if separate from the confined blasts) is unknown at this time. It can only be assumed that these "other" pressures were incorporated into recorded values.

2. Shot Patterns

The October 2003 work consisted of a second round of rock removal to assure that the planned channel grade was obtained. This action was conducted to remove high rock points remaining from the first round of shooting to achieve the proposed pay grade. A planned pattern deployment positioned the drilling barges using GPS surveying equipment. Rock above the pay grade was drilled and shot. When rock was not encountered on the pattern above the pay grade, there was no need to place any blasting agent.

To prevent the escape of gas and resultant explosive force each blast hole is "stemmed" with gravel or similar materials after the explosives are placed and the Det-Cord is connected. The type and length of stemming are important measures for confinement. Confinement is an important aspect of reducing the pressure by restricting riffling into the water channel above the shot hole. Previous contact indicated that 5/8-inch to ¾-inch, crushed stone was used as stemming with a minimum stemming length in rock of 30 inches.

3. Timing and Charge Weight per Delay

The delay sequence was resolved by a predetermined evaluation plan and placed by the number of holes drilled in each range and the number of ranges for the particular shot. Thus the actual delay timing deployed was a process of both the plan and the actual holes that were found above the pay grade.

The charge weight per delay is an important element of the blast vibration and water-borne pressure waves. The maximum charge weight per delay is the parameter that will likely be the predictor of the maximum vibration in particle velocity and the maximum water pressure. The maximum charge weight per delay is the largest weight of blasting agents shot at a single delay interval of less than 9 milliseconds (ms), 0.009 second (s). The largest weight may be attributed to a single shot hole or several shot holes with the same delay timing. It so happens that the recorded shots were from single shot holes with maximum charge weights per delay in the 70 to 90 lb per delay range.

4. Shots Used for this study

Table 4.2.1 presents shot locations for shots recorded by the pressure transducer. In addition to locations, table 4.2.1 also presents the shot dates, diagonal corner locations, recording action, and transducer locations. Table 4.2.2 gives shot data important for calculating scaled distance to the leading transducer array or the lagging (further) transducer. Four shots were successfully recorded: 2MB-010, -014, -021 and -022.

Table 4.2.1
KVK Joint Venture Shot & Transducer Locations

Blast 2MB-#	Oct 2004 Date	Borehole Corner Position		Shot Corners		Record Action	Transducer Azimuth From shot	Transducer Locations	
		L-Rng	X-Rng	N	E			N	E
008	Tu, 21	N	W	593,952	659,713	Pretriggered-no info	east	594,569	659,626
		S	E	593,967	659,680			594,715	659,681
009	Tu, 21	N	W	593,712	659,559	Not permitted			
		S	n/a	593,717	659,538				
010	W, 22	N	W	593,706	659,721	**record**	east	594,403	659,767
		S	n/a	593,759	659,622			594,564	659,778
011	W, 22	N	E	593,662	659,648	Below threshold	west	592,948	659,600
		S	W	593,523	659,619			592,794	659,584
014	Th, 23	n/a	E	593,548	659,814	**record**	west	593,082	659,720
		n/a	W	593,540	659,812			592,929	659,662
020	Tu, 28	N	n/a	594,363	659,779	Below threshold	east	594,642	659,817
		S	E	594,412	659,730			594,699	659,673
021	W, 29	N	W	594,431	659,747	**record**	east	594,932	659,751
		S	n/a	594,519	659,663			595,070	659,667
022	Th, 30	N	E	592,417	659,518	**record**	east	592,840	659,629
		S	W	592,343	659,430			592,990	659,613

Table 4.2.2
KVK Shot Operations & Data

Shot-test	MxCharge Wt/Delay (lb)	Charge Distribut'n	Hole/ Range Ref	Lead T Dist (ft)	Lag T Dist (ft)	Lead Scal Dist (ft-lb1/2)	Lead Scal Dist (ft-lb1/3)	Lag Scal Dist (ft-lb1/2)	Lag Scal Dist (ft-1b1/3)	Data Result
008										Pre-triggered - no info
010	**73**	single	8/ R 31	660	820	77	158	96	196	**record**
011	133	2 – 24'	2/ R 19	580	740	56	122	72	156	Below threshold
Open wtr 1										Signaling problem*
Verift'n 1	cap	single		5.6						~ 5.58' from cap at 5' depth
Verift'n 2	cap	single		5.6						~ 5.58' from cap at 5' depth
014	**72**	single	15/ R 47	480	640	57	115	75	154	**record**
020	54	2 – 8'	2/ R 44	250	300	48	83	58	100	Below threshold
021	**87**	single	16/ R 46	500	640	54	113	69	144	**record**
022	**73**	single	16/ R 40	570	700	67	136	82	167	**record**
Open wtr 1										JV could not shoot; small charge below threshold or outside of time range.

* not ready to record when shot

B. Recording the Shots

The recording system for acquiring water-borne pressures is a sophisticated electronic set of systems. The recording of pressures must respond to pressure changes in the 1 to 5 microsecond (μs, 0.000001 s) range. The analog signal must be digitized and stored a long distance from the submerged transducer. Furthermore, the system must be initiated either by a signal from the actual shot initiation or by a pressure rise at one of the recording transducers. The latter is termed the trigger-source transducer. Since a non-electric shot initiation system was employed for safety reason the recording vessel was well removed from the shot hole pattern, therefore, a trigger-source transducer was required. Images of the hardware are included below and in Appendix C. The pressure transducer system consists of the transducers themselves, cabling, and array configuration. The transducers are typically calibrated before and after use. Verification shots show that the calibration is approximated and the system is properly recording. The beginning, two verification shots were conducted on 23 OCT 03. An ending verification was not available from the Joint Venture. The ending verification would have been performed on the remaining three transducers still active at the end of the program. The transducers used and recorded file names for each shot are provided in Table 4.2.3.

The transducers and file names for the two, beginning verification shots are provided at the bottom of Table 4.2.3. The calibration data and verification approximation are provided in Table 4.2.4.

Pressure transducer used in blast monitoring array.

A suitable transducer array support line was constructed for this study. Three transducer cable

Transducer array chain used for blast monitoring.

positions were created for the leading, or closer, suspension to the shot. One mid-depth position was suspended for the lagging, or further, suspension from the shot. The photograph record (Appendix C) provides images of the transducers, array cable, and array placement.

The transducers were taped with plastic electrical tape to 3/8-in link, steel chain and square reinforcement rods holders. The reinforcement holders allow the transducers to be suspended in approximately the center of the square. This prevents a pressure “shadow” from affecting the suspended transducer relative to a transducer taped directly the side of a rope or chain. The depths to each transducer on the two suspensions were relative to the top of a 3-ft long, 2-in diameter, white PVC pipe. Eyes for pumpkin buoys on part of the PVC pipe containing the start of the cable allowed attachment to both buoys and the array line. During deployment the top of the PVC cable to the water line provided the depth of each transducer.

An array line was created for quick deployment of buoys, anchors and transducers. The 200-ft long line was braided, ¾-in, yellow rope. Each end of the array line had quick opening hasps. There were two positions along the array line, 150-ft apart loose, for hasp connection of the transducer suspension chains. Hasps about 25-ft apart were zip tied into the braided array line to hold the transducer cable lines leading to the recording vessel.

The transducer skiff would take the GPS position and PVC top to water line length following a shot. Then the skiff would reverse the process of removing the transducer cables from the support vessel and disconnect and store the transducer chains in the trays. The Hudson would then remove anchors for the array line. Deployment and recovery would each take 60 to 90 minutes depending on wind and tidal flow conditions.

Placement of monitoring apparatus along support line by crew in support vessel (skiff).

Table 4.2.3
KVK Pressure Transducer Data

Shot File ext	Transducer Depth (ft)				Transducer #/ File Names				Data Result
	Lead top	Lead mid	Lead btm	Lag mid	Lead top	Lead mid	Lead btm	Lag mid	
Ref depth	7.1	28.0	51.2	27.1					
010	5.6	26.4	49.7	24.8	2708	2329	2632	2714	**Record** Level 37.8 mV
.wft					22O04	22O01	22O02	22O03	
.pcx					0102708	0102329	0102632	0102714	
011	5.6	26.4	49.7	24.8	2708	2329	2632	2714	Below threshold
014	5.6	26.4	49.7	24.8	2708	2333	2632	2714	**Record** Level 50.6 mV
.wft					23O12	23O09	23O10	23O11	
.pcx					0212332	0212333	0212693	0212714	
020	5.5	26.3	49.6	25.5	2332	2333	2693	2714	Below threshold
021	5.1	26.0	49.2	25.2	2332	2333	2693	2714	**Record** Level 50.6 mV
.wft					29O01	29O02	29O03	29O04	
.pcx					0212332	0212333	0212693	0212714	
022	5.7	26.6	49.8	25.7	2332	2693		2714	**Record** Level 50.6 mV
.wft					30O01	30O02		30O03	
.pcx					0222332	0222693		0222714	
					1	**2**	**3**	**4**	
Verift'n 1	5.0	5.0	5.0	5.0	2708	2333	2632	2714	~5.58' from cap at 5' depth Level 142 mV
.wft					23O01	23O02	23O03	23O04	
.pcx					CAP 1				
Verift'n 2	5.0	5.0	5.0	5.0	2708	2333	2632	2714	~5.58' from cap at 5' depth Level 142 mV
.wft					23O05	23O06	23O07	23O08	
.pcx					CAP 2				

Table 4.2.4
KVK Pressure Transducer Calibration

Transducer	Type	Channel	Calibration (psi/V)	Verftn 1 (V)	Verftn 2 (V)	Verftn 1 (psi)	Verftn 2 (psi)
2708	138A05	1	927	0.5144	> 1.0291	Limiting Test	
2329	138A05	2	960				
2632	138A05	3	1,031	0.1827	0.1728	188	178
2714	138A01	4	216	0.6808	0.7373	147	159
2333	138A01	2	206	0.8504	0.8976	175	185
2332	138A01	1	208				
2693	138A01	3, 2	200				

Figure 4.2.3 depicts the transducer array, while Figure 4.2.4 depicts the transducer array as deployed from the recording vessel. Figure 4.2.5 presents the blast and blast monitoring locations for this study. Table 4.2.2 presents the lateral distance from each shot's maximum charge weight per delay shot hole to the leading and lagging chain suspension positions. Table 4.2.3 provides the depth below the water line for each transducer.

1. **Pressure Recording**

A four-channel Nicolet Model 440 Digital Recording Oscilloscope transformed the analog voltage data to digital points. The voltage data from respective transducers was recorded on 3.5-in diskettes.

The oscilloscope was set to record the time interval between data points and the total length of record. The range of voltage to be recorded was established. A high range would not have sensitive intervals. A low range could be over-scaled and data lost beyond the range.

The oscilloscope allows a trigger for the initiation of data collection or may trigger data collection when the source channel exceeds a threshold voltage. The latter was required so the source channel and threshold voltage needed to be selected to acquire the voltage data. When the trigger source voltage is exceeded, all the transducers' inputs are recorded

2. **Pressure Data Calculation**

The transducer voltage file names (.wft extensions) for each shot and the verifications are provided in Table 4.2.3. Every record is provided in Electronic Appendices on compact disk.

Vu-Point II software, Version 2.0 (Maxwell Laboratories, Inc.) was used to scale voltage ".wft" digital files to create pressure data. This software was also used to create graphic ".pcx" files. These graphic files may be printed. The graphic file names are provided in Table 4.2.3. The calibration factor for a given transducer is provided in Table 4.2.4. The maximum pressure for each transducer and shot are given in Table 4.2.5 with other data. The pressures are recorded to two significant digits. One to three shot-transducer pressure wave records (.pcx extensions) are provided in Electronic Appendices on compact disk. Figure 4.2.6 depicts the full recorded record, as an example, for the leading mid-depth transducer and the lagging mid-depth transducer of Shot 2MB-014. Figure 4.2.7 depicts the location of the monitoring stations relative to Shot 2MB-014. Figures 4.2.8a and 4.2.8b provide the Drill Log and Blast Reports for the shot.

Table 4.2.5
KVK Shot & Water-borne Pressure Data

Shot	# Holes Shot	Delay Interval (s)	Timing of Max Wt. (s)	Record Length (s)	Lead Scale Dist. (ft-lbs 1/3)	Maximum Pressure (psi) during Record Length				Calculated Open-Water Pressure (psi)
						lead top	lead mid	lead btm	lag mid	
010	25	.100 - .742	0.330, 0.492	0.700	158	**29**	**14**	Stray	**7.1**	71
014	2	.517 - .617	0.517	0.360	115	**27**	**21**	**26**	**18**	101
021	28	.100 - .480	0.400	0.900	113	3.4	Stray	**16**	**20**	104
022	39	.075 – 1.042	0.492	0.900	136	5.1	**19**	None	**14**	84

Appendix B presents a complete set of transducer records and Drill Log and Blast Reports for the study.

High-quality, maximum pressure values are noted in bold in Table 4.2.5. The recorded pressures are quite low and are the lowest levels of maximum pressure recordings that USACE has monitored. The data were judged to be of high quality when they met consistency tests and corroborated with other recordings. Some transducer records did not record the high-pressure waveform. The maximum pressure for these poor records is provided in Table 4.2.5, but the values are not shown in bold. The leading top transducer for both Shots 021 and 022 seem too low relative to the other recordings for the same shot and the other top transducer on different shots. A stray current or noise issue for the circuit caused a mis-recording of pressure for the leading bottom transducer of Shot 010 and for the leading midlevel transducer of Shot 021. These two shot-transducer records are listed as "stray" in Table 4.2.5. The graphs of both transducers show that neither transducer has a typical waveform relative to the other transducers.

The data of Table 4.2.5 indicates that the record length for three shots (010, 014, 021) exceeded the interval of the shot hole delays. Therefore, if the first shot hole in time caused the threshold voltage to be exceeded the entire record could still be recorded. In shot 022, the timing of the maximum charge weight per delay would be recorded whether or not the first shot hole started the voltage recording. So the maximum pressure should be recorded regardless for Shot 022.

Other measures of impact, both impulse and energy flux density, were to be calculated from the pressure wave data. The complexity of the waveform and the high level of noise relative to the measured pressures did not allow evaluation of either impulse or energy flux density. Both measures would require integration of the pressure-time history over a defined length. The time length for integration is so short that it is not meaningful or that produced pressure only modestly exceeds the background noise with the lesser reverberation for impulse and energy. As noted in Hempen (1993), "complete digital recording of shock-wave pressure is the only means certain of proper correlation development with faunal impact." Yet at these low amplitude pressures, the other two measures have neither meaning nor impact if the full waveform cannot be resolved.

The Leading Transducer suspension distance from the shot's location of the maximum charge weight per delay hole was used to determine the scaled distance. The scaled distance allows computation of the theoretical single, open-water shot's pressure for an equivalent charge weight and distance. The equation from Cole (1948) was used to resolve the open-water shot's pressure provided in the last column of Table 4.2.5. The hard rock surface and shallow water depth may act as a wave-guide to increase the pressure above the calculated pressure for the open-water equivalent.

Unfortunately, the single open-water test provided by the Joint Venture had insufficient operational communication to record the small charge. The charge would have needed to have been closer to the transducers to have recorded pressures. A second opportunity was not available to have a test of an open-water shot.

4.3 Study Results

Actual maximum pressures were successfully recorded in the adverse (radio-wave) environmental conditions of this channel reach. The maximum, high-quality pressures shown in bold in Table 4.2.5 are relatively small compared to the theoretical value of an equivalent charge weight, open-water shot. Unfortunately, actual recording of an open-water shot for confirmation of comparison procedures was unsuccessful on the only attempt.

The complex pressure waveform does not allow integration of the pressure record to determine impulse and energy flux density.

4.4 Discussion

A. Study Limitations

There were some obstacles to overcome in coordination and capture of the blast pressure-wave monitoring. The primary difficulties were: weather conditions, coordination of a shot's exact timing, interference in the noisy radio-frequency environment, cable saturation/lowering of the dielectric capacity, and low blast pressure released into the water column. The team was operationally able to record shots from about 21 through 30 October 2003. Pre-triggering and interference problems prevented the first shot (2MB-008) from being captured, but relative to later shots the Shot 008 pressure values were likely below the triggering level to be recorded. Pressure waves have been recorded that are attributed to the blasting. The system was available to record blasting but did not trigger recording for several shots: 2MB-008 (22 Oct 03), 2MB-011 (22 Oct 03), and 2MB-020 (28 Oct 03). It has been judged that the system was functioning, but that the pressures were below the trigger levels to record pressure data. Low-threshold triggers are required because there is not a physical link to the blast initiation. Pressure waves were recorded for shots: 2MB-010 (22 Oct 03), 2MB-014 (23 Oct 03), 2MB-021 (29 Oct 03), and 2MB-022 (30 Oct 03). One attempt to record a small charge, open-water blast was unsuccessful due to unsuccessful communication of the timing and perhaps too great of a distance between the shot location and transducers. Another open-water shot could not be coordinated. For detailed description of limitations see Appendix A.

B. Discussion of Results

The maximum pressures of four shots were successfully recorded. Quality, maximum pressures are shown in bold in Table 4.2.5. The maximum pressures and their waveforms show very short duration peaks that may be related to destructive interference from a complex shot pattern. There is reasoning that having a uniform maximum charge weight per delay could reduce some of the maximum peaks, but this is a hypothesis. For several of the shots the maximum charge in one shot hole was several multiples of most other holes.

1. Blast Pressures

The maximum pressures from the confined shooting are significantly lower than theoretical open-water shot pressures. Radiation of the wave energy into rock reduces the available energy reaching the water column. The pressures entering the water column are well below those pressures that typically propagate away from open-water (unconfined by solid media that may radiate the energy away with less harm) charges relative to charge weight per delay.

The maximum pressures recorded are related to the maximum charge weight per delay. This cannot be directly correlated due to the complexity of shot pattern and potentially to the confinement of the charge within the rock. The number of drill holes and the average charge weight per delay varied among shot patterns. Uniform charge weight per delay would likely have had less variable impact on stunning and killing fish. [When there is a need for a drill hole with a large charge weight per delay relative to other array borings of average charge weight per delay, the position of the boring with the maximum charge weight per delay is important. At the outer perimeter the boring the maximum charge weight per delay will extend the kill radius significantly in the direction away from the shot pattern's borings. The boring with the maximum charge weight per delay will have a lower impact when it is positioned near the center of the shot pattern. The lowered impact is due to the kill radius of the worst impact drill hole needing to surpass the kill radii of the surrounding borings with smaller kill zones due to their average charge weights per delay.

The maximum pressure clearly is unrelated to the total weight of blasting agents shot. Shot 014 had only 98 lb total explosive weight but had comparable maximum pressures to other shots with many multiples for the total charge weight. The shot pressures were relatively uniform, while the shots varied significantly in total charge weight.

2. Blasting Impact: Fish Mortality

Hubbs and Rechnitzer (1952) determined that the lethal threshold peak pressure for a variety of marine fish species exposed to dynamite blasts varied from 40 psi (280 kilopaschals, kPa) to 70 psi (480 kPa). Keevin (1995) found no mortality or internal organ damage to bluegill exposed to a high explosive at pressures at or below 400 kPa (60 psi). Canadian guidelines for the use of explosives have established the conservative value of 100 kPa (15 psi) as the "theoretical lethal range" (i.e., the range, or distance, over which the overpressure exceeds 100 kPa or 15 psi).

Fish kill was likely very close to the placed charges. The actual limits of the kill radii cannot be determined without caged fish. Stunned and killed fish were recovered by handnet from the surface. Many fish noted at the water surface after a shot may have been only stunned and may have recovered except for immediate predation by gulls (see photos below and Appendix C). The NY District had initially planned to trawl for dead and stunned fish after each recorded blast. Several issues arose which prevented those plans from being executed. First, safety guidelines prevent any craft from approaching the blast area for about 10 minutes *after* the blast due to a loss of buoyant force in the water caused by release of gas from the explosion. By the time the "all clear" is sounded, the currents in the KVK had most likely widely dispersed fish located below the surface. Second, the complexity and logistics of setting up each shot pattern and need for the

View of bird predation on killed/stunned fish immediately following blast.

contractor to make frequent changes in the blasting schedule made keeping a contracted boat and crew on standby infeasible.

There are a number of physical attributes of the pressure waveform from the confined shots measured in this study that may suggest that mortality would be lower than indicated by the peak-pressure measurements. The impulse of a pressure wave gives the best indication of potential organ damage and mortality (Keevin and Hempen 1997). The impulses from the KVK confined shots were unable to be assessed for the lowered amplitude pressures within the rapidly alternating noise field.

The rapid oscillation from a high, brief overpressure and a moderate, but longer, underpressure associated with detonation of high explosives in the water column is most probably responsible for fish mortality. This oscillation in waveform is responsible for the rapid contraction and overextension of the swimbladder resulting in internal damage and mortality.

It has been suggested that the negative phase (relative to ambient) of the pressure wave is responsible for organ damage (particularly the swimbladder) and mortality (Keevin and Hempen 1997). This conclusion was reached by the observation of swimbladders that were burst outward. For example, postmortem observations of striped bass (*Morone saxatilis*) and trout (*Cynoscion regalis*) found “the edges of holes in the swim bladder were turned outward and that blood from broken vessels in the wall of the bladder had been blown into the abdominal cavity” (Anonymous 1948). During the current study, the abrupt compressing pressures, usually associated with the detonation of high explosives, were reduced in amplitude and negative pressures were not observable relative to the background noise.

The more conservative pressure of 40 psi from Hubbs and Rechnitzer (1952) was used as a basis of mortality, even though their range extends to 70 psi and Keevin (1995) found pressures below 60 psi did not impact small, fresh-water fish. This is also a conservative standpoint because the waveform of the tested citations were from open-water tests and not from similar confined shots that did not have clear extension phases for measurable impulse and energy measures. Mortality is presumed when fish are exposed to 40 psi, but not killed below 40 psi. There is some evidence, as stated in preceding paragraphs, that confined shots would not have mortality pressures as low as those open-water shots.

The recorded data of Table 4.2.5 clearly demonstrates that no fish would have been killed at the recorded distances; 480 to 660 feet (Table 4.2.2), from the KVK confined shots. Theoretically, equivalent open-water shots would have killed fish beyond these distances. As the pressures required to trigger recording for Shot 020 did not exceed 34 psi, this recording distance, 250 feet, would not have been lethal.

Cole’s equation for the open-water pressures may be manipulated using the lethal pressure of 40 psi. The mortality radius for single, open-water shots, MR_{OW}, is:

$$MR_{OW}\text{ (feet)} = 260\, w_{OW}^{\ 1/3},$$

where

w_{OW} = the maximum charge weight (in pounds) per delay of a single, open-water blast.

The data set of Table 4.2.5 for KVK confined, channel rock-removal blasting may be resolved to an equivalent form of Cole’s equation. The assumption, which is conservative for mortality, is that the attenuation factor is similar for both explosive positions; the attenuation should be greater for rock. Insufficient information has been collected to resolve the rock attenuation exponent for this location, although the Joint Venture's records may have sufficient material to resolve the attenuation. The maximum pressure, p_C, from a single confined charge for the KVK data is:

$$p_C \text{ (psi)} = 5{,}600 \; SD_C^{\,-1.13},$$

where

SD_C = the confined scaled distance and $SD_C = d / (w_C^{\,1/3})$,
d = is the distance from the single confined blast to the point of pressure value, p_C,
w_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

The mortality radius for confined shots from the KVK data may be resolved from the confined pressure equation and using the lethal pressure of 40 psi. The mortality radius for single, confined shots, MR_C, is:

$$MR_C \text{ (feet)} = 80 \; w_C^{\,1/3},$$

where

w_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

Theoretical mortality radii are computed and listed in Table 4.2.6. The table lists (for the six shots where the transducer array was in place) the number of drill holes shot and the maximum charge weight per delay of each shot. The table provides the leading and lagging distances for each shot from the boring with the maximum charge weight per delay to the transducers. For three shots the boring with the maximum charge weight per delay was the closest boring to the transducer array. For Shots 014, 021 and 022 the typical 25-lb charged boring was the closest boring to the transducer array. Both MR_C and MR_{OW}, which are theoretically determined, are given in Table 4.4.1. MR_C and MR_{OW} for the typical 25-pound charge in a boring are 230 and 760 feet, respectively. For most shots there was a field of borings all with 25-lb charges, except for one to three drill holes with a larger maximum charge weight per delay. The noted MR_C may be more conservative, or larger, than the actual mortality radius, as noted above. MR_C is less than one third the corresponding radius of equivalent single, open-water blasts. The complexity of the shot pattern and heterogeneity of the rock cause the actual pressures to have greater amplitudes than pressures from a single shot.

Table 4.4.1
Mortality Distances

Shot	# Holes Shot	Max Charge Wt/Delay (lb)	Lead T Dist (ft)	Lag T Dist (ft)	M Radius Confined (ft)	M Radius Open-wtr (ft)
010	25	73	660	820	330	1,100
011	17	133	580	740	410	1,300
014	2	72	470	630	330	1,100
020	19	54	250	300	300	980
021	28	87	500	640	350	1,200
022	39	73	570	700	330	1,100

4.5 Conclusions from Blast Monitoring

Pressure waves from the actual confined shots of the KVK rock removal program were recorded. The pressure waves and their maximum amplitudes were determined for four shots. The pressures from the confined shots were significantly lower than equivalent shots theorized as detonated in the water column.

An equation was approximated to predict maximum pressures from the confined shooting of the KVK rock removal. Theoretical mortality relations were resolved for both confined and open-water shooting. The confined mortality radii may overestimate the kill zones for fish, as there is insufficient data on fish kill at this location and other measures of impulse and energy, which could be used to corroborate the maximum pressure impacts, could not be attained. The mortality radii for the performed confined blasting are much smaller than equivalent open-water mortality radii.

5.0 PROGRAM CONCLUSIONS

5.1 Dominant Fish Species

The fish species that dominated Harbor Complex collections included striped bass, white perch, winter flounder, Atlantic tomcod, spotted hake, bay anchovy, Atlantic silverside, Atlantic menhaden, bluefish, spot, and weakfish. It can be expected that these species will also be present in the KVK.

The species diversity and abundance varied seasonally. The data reviewed indicate that species diversity was low in winter collections, and increased in the spring. Species diversity was highest in the summer and fall. This pattern reflects the spring migration into and fall migration out of the area by juvenile and adult stages of many anadromous and marine species. For example, winter flounder, an important recreational and commercial species, was most abundant from November through March; though it was present in collections all year. Striped bass were present year round, but striped bass abundance peaked from January to March. Atlantic menhaden were also present year round, but this species was most abundant in samples from July through August. Table 2.4.1 presents the seasonal occurrence the fish species dominant in the sampling studies reviewed for this report.

5.2 Fish Observations During Blast Pressure Measurements

The primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, particularly the swimbladder (Wright and Hopky 1998; Keevin and Hempem 1997). Many pelagic fish possess swimbladders; this organ plays a role in buoyancy. In contrast, demersal species, such as flounder, typically do not have swimbladders and are frequently less susceptible to blast impacts.

During the Blast Monitoring study, study participants observed the types of fish that appeared at the surface following blasting events. Attempts were made to capture fish that were stunned or killed by the blast. However, heavy gull predation in the vicinity of the blast interfered with collections; gulls are opportunistic and quickly preyed upon the fish that floated to the surface. Even so, several fish species were captured by netting using a small support boat or were observed floating in the vicinity of the anchored R/V *Hudson*. Observations were as follows:

- ***21 October 2002*** – Morning shot – *Menidia* sp. (silverside) floating, striped bass (approximately 18-in. total length)

- ***22 October 2003*** – Morning shot - eel and sea robin (approximately 3- to 4-inch total length) floating; afternoon shot – striped bass (approximately 18-in. total length) and butterfish (approximately 3- to 4-in. total length)

- ***23 October 2003*** – Afternoon shot – 22 menhaden (approximately 12- to 15-in. total length) floating on surface plus one striped bass (approximately 18-in. total length)

- ***29 October 2003*** – Late morning blast – observed many *Menidia* sp. (silverside) and herring (approximately 3- to 4-in. total length) floating; support boat collected one 20-lb striped bass (stunned), three blueback herring (two at 3-in. total length and one at 8-in. total length), and one menhaden (4-in. total length).

It is likely that the species observed is reflective of seasonal patterns. It is expected that winter, spring or summer monitoring would show a difference in the species affected.

5.3 Blast pressure and Fish Mortality

The primary cause of damage in finfish exposed to a pressure shock wave appears to be the outward rupture of the swimbladder as a result of the expansive effect of the negative hydrostatic pressure associated with the reflected air-water surface wave. The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality, although water depth, substrate, depth of the fish, and size and species of fish are also important (Keevin and Hempen 1997; Wiley et al. 1981; Teleki and Chamberlain 1978). The shape of the lethal zone is dependent on the depth of the detonation. In shallow water, the horizontal extent is greater than in deep water. However, for buried explosives, the lethal zone is conical with the narrow portion of the lethal zone near the bottom expanding horizontally toward the water surface (Linton et al. 1985). This study looked to estimate the radius of this lethal zone, the mortality radius, based on a derived relationship between confined blasts and open-water blasts.

Using a conservative pressure value of 40 psi as the basis for mortality (Hubbs and Rechnitzer 1952), an equation was approximated to predict maximum pressures from the confined shooting of the KVK rock removal. Based on the resulting data, it appears that the mortality radii for the performed confined blasts are much smaller than equivalent open-water mortality radii. This is demonstrated by the data recorded for the shots listed in Table 4.2.5. No fish would have been killed at the recording distances for these shots (480 to 660 feet) as the maximum pressures fell below the lethal pressure of 40 psi. A theoretical estimate of the pressure and impact of the "average" blast event monitored during this study would result in a pressure of about 90 psi with a kill radius of about 375 feet. The calculated open water charges would have ranged in pressure from 71 to 104 psi, therefore theoretical open water shots would have killed fish within and beyond these distances. Although these data are conservative, it should be noted that the calculated confined mortality radii may overestimate the kill zones for fish, as there was insufficient data on fish kill at the study location, and other measures of impulse and energy, which could be used to corroborate the maximum pressure impacts, could not be attained. While it is stated elsewhere in this report that fish "close" to the blast point would be killed, it is not possible to quantify the kill zone radius based on data collected during this study or other studies consulted as part of the literature review.

Review of blasting literature revealed that the position of drill holes with maximum charge weights within arrays of multiple charge weights affects the kill radius. When drill holes with maximum charge weights are located at the outer perimeter of an array, the kill radius is significantly larger. However, when maximum charge weight borings are positioned near the center of the shot pattern, the impact is diminished. It appears that the pressure waveform of the maximum charge is dampened by those of the surrounding lesser charges.

In conclusion, the blast pressure monitoring data implies that impacts on the fish may be diminished through the use of arrays configured with maximum charge weights located in the middle of lesser charge weights. The data also implies that the confined charges used in the KVK Blasting Program appear to have less of an impact on fish than would equivalent open water charges. However, without completion of a caged fish study, quantitative estimates and/or calculations of mortality radii may not be made.

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Section 2

Contained within Text.

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APPENDIX 2

Transportation of Explosives Requirements

Transportation of Explosives Requirements

GENERAL REQUIREMENTS FOR THE STORAGE, USE, AND TRANSPORTATION OF EXPLOSIVES

BOND REQUIRED FOR BLASTING

Before a permit is issued for the storage, sale, transportation, disposal, or use of explosives or blasting agents, the applicant shall file with the JAXPORT a bond or evidence of a liability insurance policy in the amount of at least **two million dollars ($2,000,000)** combined single limit for bodily injury and property damage. This insurance policy shall become available for the payment of any damage arising from the acts or omissions of the applicant, his agents or his employees in connection with the storage, transportation, disposal, or use of explosives or blasting agents.
Bonds or liability insurance policies may be for a specific operation or for an entire year provided that the applicant shows evidence that the bond or liability insurance policy is in continuing effect.

If there is a fee associated with this permit, the fee is non-refundable. Reference the JAXPORT fee schedule for the applicable permit cost.

General Requirements:

1. **Manufacturing:** The manufacture of explosives or blasting agents shall be prohibited. This shall not apply to hand loading of small arms ammunition for personal use when not for resale.
2. **Storage:** The storage of explosives and blasting agents is prohibited within the limits established by law as the limits of the district in which such storage is to be prohibited, except for temporary storage for use in connection with approved blasting operations, provided; however, this prohibition shall not apply to wholesale and retail stocks of small arms ammunition, explosive bolts, explosive rivets or cartridges for explosive-actuated power tools in quantities involving less than 500 pounds of explosive material. The overnight storage of explosives or blasting agents shall be prohibited in all areas of Prince William County except by special use permit, as defined in JAXPORT Zoning Ordinances with amendments.
3. **Quantity Control:** The fire official may limit the quantity of explosives or blasting agents to be permitted at any location.
4. **Sale and Display:** A person shall not sell or display explosives or blasting agents on highways, sidewalks, public property, or in places of public assembly.
5. **Reports:**
   a. JAXPORT shall be immediately notified by telephone of the loss or theft of any explosives. This verbal notification shall be immediately followed by a letter to JAXPORT giving complete details as to type, amounts, manufacturer and all other relevant facts.
   b. If at any time explosives are found not properly stored in a magazine, it shall immediately be reported to the JAXPORT who will take possession thereof for the purpose of safeguarding or disposal of such explosives.

STORAGE OF EXPLOSIVES

If there is a fee associated with this permit, the fee is non-refundable. Reference the JAXPORT fee schedule for the applicable permit cost.

General: Explosives, including special industrial high explosive materials, shall be stored in magazines, which meet the requirements of this article. This shall not be construed as applying to wholesale and retail stocks of small arms ammunition, explosive bolts, explosive rivets or cartridges for explosive-actuated power tools in quantities involving less than 500 pounds of explosive material. Magazines shall be in the custody of a competent person at all times who shall be at least 21 years of age and who shall be held responsible for compliance with all safety precautions. A certified blaster shall be the sole possessor of keys to locks on fence gates and magazine locks.

1. **Control in wholesale and retail stores:** The storage of or display of explosives and blasting caps in wholesale and retail stores is prohibited.
2. **Magazine clearances:** Class I and Class II magazines shall be located away from inhabited buildings, passenger railways, public highways, and other magazines in conformance with the American table of distances for storage of explosives as approved by the Institute of Makers of Explosives and revised in 1991.

3. **Magazine Construction:**
   a. Magazines shall be constructed and maintained as outlined in N.F.P.A. 495, 1996 edition.
      (1) Class I magazines shall include Type 1; Type 2, Outdoor Box Magazine; and Type 3, Vehicular Magazine as outlined in N.F.P.A. 495 except the latter type shall meet all lock requirements for a Type one magazine
      (2) Class II magazines shall be constructed of 2 inch tongue and grooved hardwood, covered on the outside with No. 20 U.S. standard gage sheet iron or aluminum or of all metal construction with side, bottom, and cover of sheet metal lined with 3/8 inch plywood or the equivalent. Class II magazines shall have a minimum of 2 locks, with different keying for each lock, plus locks shall be protected by steel hoods that are installed in a manner to prevent insertion of bolt cutters.
4. **Weather Resistance:** Magazines for the storage of explosives shall be weather resistant and properly ventilated and when used for storage of Class A explosives other than black powder, blasting caps and electric blasting caps, shall also be bullet resistant.
5. **Magazine Heat and Light:** Magazines shall not be provided with artificial heat or light, except that if artificial light is necessary, an approved electric safety flashlight or safety lantern shall be used.
6. **Safety Precautions:** Smoking, matches, open flames, spark producing devices and firearms shall be prohibited inside or within 50 feet of magazines. Combustible materials shall not be stored within 50 feet of magazines.
7. **Surrounding Terrain:** The land surrounding magazines shall be kept clear of brush, dried grass, leaves, trash, and debris for a distance of at least 25 feet.
8. **Locking Security:** Magazines shall be kept locked except when being inspected or when explosives are being placed therein or being removed there from.
9. **Magazine Housekeeping:** Magazines shall be kept clean, dry, and free of grit, paper, empty packages, and rubbish.
10. **Separation of Detonators and Explosives:** Blasting caps, electric blasting caps, detonating primers, and primed cartridges shall not be stored in the same magazine with other explosives.
11. **Explosive Unpacking:** Packages of explosives shall not be unpacked or repacked in a magazine nor within 50 feet of a magazine.
12. **Magazine Contents:** Magazines shall not be used for the storage of any metal tools or of any commodity except explosives, but this restriction shall not apply to the storage of blasting agents, blasting supplies, and oxidizers used in compound blasting agents.
13. **Unstable Explosives:** When an explosive has deteriorated to an extent that it is an unstable or dangerous condition, or if nitroglycerin leaks from any explosive, then the person in possession of such explosive shall immediately report the fact to the fire official and upon his authorization shall proceed to destroy such explosives and clean floors stained with nitroglycerin in accordance with the instructions of the manufacturer. Only experienced persons shall do the work of destroying explosives.
14. **Class I Magazine Warnings:** Property upon which Class I magazines are located shall be posted with signs reading EXPLOSIVES--KEEP OFF. Such signs shall be located so as to minimize the possibility of a bullet traveling in the direction of the magazine if anyone shoots at the sign.
15. **Class II Magazine Warnings:** Class II magazines shall be painted red and shall bear lettering in white, on all sides and top at least three inches high reading EXPLOSIVES--KEEP FIRE AWAY.
16. **Magazine Use:** Class I magazines shall be used for the storage of explosives when quantities are in excess of 50 pounds of explosive material and for the overnight storage of explosives regardless of the quantity.
17. **Class II Magazine:** Class II magazines may be used for temporary storage of explosives at the site of blasting operations where such amount constitutes not more than one day's supply for use in current operations. All explosives not used in the day's operation shall be returned to the Class I magazine at the end of the workday for overnight storage. In no case shall a Class II magazine be used for overnight storage.
18. **Fencing:** An 8 foot chain link fence or a 6 foot chain link fence with three strands of barbed wire around the top is recommended around a Class I magazine installation. It is also recommended that this fence have a gate in it equipped with casehardened locks and hasps.
19. **Records:** Daily records shall be kept as to the amount of explosives received from a supplier and delivered to the magazine. Also, a daily record shall be kept of the explosives removed from the magazine for daily use and the amount of explosives returned. This record will be kept within the magazine so that on inspection of the magazine, accountability for all explosives can be made. The accountability of explosives shall be broken down as to the different types stored and used. Forms for these records shall be approved by the Fire Marshal.

STORAGE OF BLASTING AGENTS AND SUPPLIES

General: Blasting agents or oxidizers, when stored in conjunction with explosives, shall be stored in the manner set forth in Section 3304 of the International Fire Code for explosives. The quantity of blasting agents or oxidizers shall be included when computing the total quantity of explosives for determining distance requirements.

1. **Storage Location:** Buildings used for storage of blasting agents separate from explosives shall be located away from inhabited buildings, passenger railways and public highways in conformance with the American table of distances for storage of explosives as approved by the Institute of Makers of Explosives and revised in 1991.
2. **Storage Housekeeping:** The interior of buildings used for the storage of blasting agents shall be kept clean and free from debris and empty containers. Spilled materials shall be cleaned up promptly and safely removed. Combustible materials, flammable liquids, corrosive acids, chlorate's, nitrates other than an ammonium nitrate or similar materials shall not be stored in any building containing blasting agents unless separated by construction having a fire resistance rating of not less than one hour. The provisions of this section shall not prohibit the storage of blasting agents together with non-explosive blasting supplies.
3. **Oxidizers and Fuels:** Piles of oxidizers and buildings containing oxidizers shall be adequately separated from readily combustible fuels.
4. **Oxidizer Handling:** Caked oxidizer, either in bags or in bulk, shall not be loosened by blasting.

TRANSPORTATION OF EXPLOSIVES

General: Explosives shall not be transported on public conveyances. When transported in vehicles, the following precautions shall be observed.

1. **Vehicle Design:** Vehicles used for transporting explosives shall be strong enough to carry the load without difficulty and shall be in good mechanical condition. If vehicles do not have a closed body, the body shall be covered with a flame proof and moisture proof tarpaulin or other effective protection against moisture and sparks. Such vehicles shall have tight floors, and exposed spark-producing metal on the inside of the body shall be covered with wood or other non-sparking material to prevent contact with packages of explosives. Packages of explosives shall not be loaded above the sides of open-body vehicles.
2. **Vehicle Prohibitions:** The attachment of any type of trailer behind a truck, a tractor-semi-trailer or truck-full-trailer combination for transporting explosives is prohibited. Explosives shall not be transported on any pole trailer.
3. **Vehicle Restrictions:** Vehicles containing explosives shall not be taken into a garage or repair shop for repairs or storage.
4. **Vehicle Contents:** Only those dangerous articles authorized to be loaded with explosives by DOT 49CFR shall be carried in the body of a vehicle transporting explosives.
5. **Vehicle Inspections:** It shall be the duty of the person to whom a permit has been issued to transport explosives over the highway of the jurisdiction to inspect daily those vehicles under such authority and employed for this purpose to determine that:
   a. Fire extinguishers are filled and in operating condition;
   b Electric wires are insulated and securely fastened;
   c. The motor, chassis, and body are reasonably clean and free of excessive grease and oil;
   d. The fuel tank and fuel line are securely fastened and are not leaking;
   e. Brakes, lights, horn, windshield wipers, and steering mechanism are functioning properly;
   f. Tires are properly inflated and free of defects; and
   g. The vehicle is in proper condition for transporting explosives.
6. **Vehicle Signs:** Every vehicle transporting explosives shall be marked or placarded on both sides, front and rear, in accordance with the requirements of DOT 49CFR
7. **Separation of Detonators and Explosives:** Blasting caps or electric blasting caps shall not be transported over the highways of the jurisdiction on the same vehicle with other explosives except by permission of the fire official. Permission is being granted by this office to transport detonators and explosives on the same vehicle provided vehicle is brought into this office for inspection and meets I.M.E. requirements.
8. **Vehicle Traveling Clearances:** Vehicles transporting explosives and traveling in the same direction shall not be driven within 300 feet of each other.
9. **Vehicle Routing:** Vehicles transporting explosives shall be routed to avoid congested traffic and densely populated

areas.

10. **Vehicular Tunnels:** Explosives shall not be transported through any completed vehicular tunnel or subway.
11. **Fire Extinguisher:** Each motor vehicle used for transporting explosive materials shall be equipped with two fire extinguishers having a rating of at least 2A:10B:C.
12. **Operating Precautions:** A person shall not smoke, carry matches, or any other flame-producing device or carry any firearms or loaded cartridges while in or near a vehicle transporting explosives, or drive, load, or unload any such vehicle in a careless or reckless manner.
13. **Spark Protection:** Spark producing metal or spark producing metal tools shall not be carried in the body of a vehicle transporting explosives.
14. **Driver Qualifications:** Vehicles transporting explosives shall be in the custody of drivers who are physically fit, careful, capable, reliable, able to read and write the English language, not addicted to the use or under the influence of intoxicants or narcotics, and not less than 21 years of age. They shall be familiar with state and municipal traffic regulations and the provisions of this article governing the transportation of explosives.
15. **Vehicle Attendant:** Vehicles transporting explosives shall not be left unattended at any time within the jurisdiction.
16. **Passenger Restrictions:** Unauthorized persons shall not ride on vehicles transporting explosives.
17. **Emergency Conditions:** The fire and police departments shall be promptly notified when a vehicle transporting explosives is involved in an accident, breaks down, or catches fire. Only in the event of such an emergency shall the transfer of explosives from one vehicle to another vehicle be allowed on highways within the municipality and only when qualified supervision is provided. Except in such an emergency, a vehicle transporting explosives shall not be parked before reaching its destination on highways within the jurisdiction or adjacent to or in proximity to any bridge, tunnel, dwelling, building, or place where people work, congregate, or assemble.
18. **Delivery:** Delivery shall only be made to authorized persons and into approved magazines or approved temporary storage or handling areas.
19. **Explosives and Blasting Agents at Terminals:** The fire official may designate the location and specify the maximum quantity of explosives or blasting agents which may be loaded, unloaded, reloaded, or temporarily retained at each terminal where such operations are permitted.
20. **Department of Transportation Regulations:** Shipments of explosives or blasting agents delivered to carriers shall comply with DOT 49CFR.
21. **Carrier Responsibility:** Carriers shall immediately notify the fire official when explosives or blasting agents are received at terminals.
22. **Notice to Consignee:** Carriers shall immediately notify consignees of the arrival of explosives or blasting agents at terminals.
23. **Consignee Responsibility:** The consignee of a shipment of explosives or blasting agents shall remove them from the carrier's terminal within 48 hours, Sundays and holidays excluded, after being notified of their arrival.

TRANSPORTATION OF BLASTING AGENTS

General: When blasting agents are transported in the same vehicle with explosives, all of the requirements of NFPA 495-1996 and DOT 49CFR shall be complied with.

1. **Vehicle Condition:** Vehicles transporting blasting agents shall be in safe operating condition at all times.
2. **Vehicle Signs:** Every vehicle transporting blasting agents shall be placarded on both sides, front and rear, as required by DOT 49CFR.
3. **Vehicle Contents:** Oils, matches, firearms, acids or other corrosive liquids shall not be carried in the body of any vehicle transporting blasting agents.
4. **Personnel Condition:** A person shall not be permitted to ride upon, drive, load, or unload a vehicle containing blasting agents while smoking or under the influence of intoxicants or narcotics.

USE AND HANDLING OF EXPLOSIVES

1. **Mixing Blasting Agents:** Buildings or other facilities used for mixing blasting agents shall be located away from inhabited buildings, passenger railways, and public highways in accordance with Chapter 33 of the International Fire Code as amended by the State of Virginia.
2. **Quantity of Mixing Agents:** Not more than 1 day's production of blasting agents or the limit determined in Chapter 33 of the International Fire Code, whichever is less, shall be permitted in or near the building or other facility used for mixed blasting agents. Larger quantities shall be stored in separate buildings or magazines.
3. **Compounding Standards:** Compounding and mixing of recognized formulations of blasting agents shall be conducted

in accordance with nationally recognized good practice.

4. **Ignition Protection:** Smoking or open flames shall not be permitted within 50 feet of any building or facility used for the mixing of blasting agents.
5. **Unpackaging Tools:** Tools used for opening packages of explosives shall be constructed on non-sparking materials.
6. **Waste Disposal:** Empty oxidizer bags shall be disposed of daily by burning in a safe manner in the open at a safe distance from buildings or combustible materials.
7. **Packing Material Disposal:** Empty boxes and paper and fiber packing materials which have previously contained high explosives shall not be used again for any purpose but shall be destroyed by burning at an approved isolated location out of doors, and any person shall not be nearer than 100 feet after the burning has started. Explosives shall not be abandoned.

BLASTING

1. **Time:** Blasting operations shall be conducted during daylight hours except when authorized at other times by the fire official.
2. **Personnel:** The handling and firing of explosives shall be performed by the person possessing a permit to use explosives and having certification as a blaster. This certification shall be approved by the Chief of the Bureau of Fire Prevention. A certified blaster on a job site can direct the handling and firing of explosives by persons under his direct supervision who are at least 21 years of age. A certified blaster must be capable of reading and writing the English language. A person shall not handle explosives while under the influence of intoxicants or narcotics. A person shall not smoke or carry matches while handling explosives or while in the vicinity thereof. An open flame light shall not be used in the vicinity of explosives.
3. **Clearance at Site:** At the site of blasting operations, a distance of at least 150 feet shall be maintained between Class II magazines and the blast area when the quantity of explosives temporarily kept therein is in excess of 25 pounds, and at least 50 feet when the quantity of explosives is 25 pounds or less.
4. **Notice:** Whenever blasting is being conducted in the vicinity of gas, electric, water, fire, alarm, telephone, telegraph, or stream utilities the blaster shall notify the appropriate representatives of such utilities at least 24 hours in advance of blasting, specifying the location and intended time of such blasting. Verbal notice shall be confirmed with written notice. In an emergency, this time limit may be waived by the fire official.
5. **Responsibility:** Before a blast is fired, the person in charge shall make certain that all surplus explosives are in a safe place, all persons and vehicles are at a safe distance or under sufficient cover and a loud warning signal has been sounded.
6. **Precautions:** Due precautions shall be taken to prevent accidental discharge of electric blasting caps from current induced by radio or radar transmitters, lightning, adjacent power lines, dust storms, or other sources of extraneous electricity. These precautions shall include:
   a. The suspension of all blasting operations and removal of persons from the blasting area during the approach and progress of an electrical storm;
   b. The posting of signs warning against the use of mobile radio transmitters on all roads within 350 feet of the blasting operations;
   c. Compliance with nationally recognized good practice when blasting within 1½ miles of broadcast or high power short wave radio transmitters.
7. **Congested Areas:** When blasting is done in congested areas or in close proximity to a building, structure, railway, highway, or any other installation that may be damaged, the blast shall be covered before firing with a mat constructed so that it is capable of preventing rock from being thrown into the air. If the blast is of such nature or in such a location that the mat by itself may not contain all debris from the blast, then the blaster shall have sufficient earthen burden placed over the blast along with the mat to contain all debris from the blast.

APPENDIX 3

Underwater Blast Pressures from a Confined Rock Removal

UNDERWATER BLAST PRESSURES FROM A CONFINDED ROCK REMOVAL DURING THE MIAMI HARBOR DEEPENING PROJECT

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ABSTRACT

Water-borne blast pressures from confined blasts were recorded as part of a submerged blasting program in Florida for channel deepening. The blasting was confined within the rock floor by stemming. Shot patterns of stemmed borings were recorded, as were two open-water shots. One hole of one shot was not confined properly, which allowed comparison of confined and a poorly confined larger charge weights per delay. The pressure data were intended to gain information on typical pressure measures from the rock removal program relative to impacts on marine organisms. Water-borne pressures from actual confined, rock-removal shots validate the hypothesis of lessened impacts to aquatic and marine biota.

INTRODUCTION

Blasting was part of the ongoing Miami Harbor Channel Deepening for the Dodge Island Widening (and Turning Basin). The blasting was confined within the rock floor to remove rock for channel deepening. Jacksonville District funded the study to take data from actual confined blasts to compare with open-water blasts. The project area is home to a number of protected, threatened, and endangered species including the Florida manatee, five sea turtle species, American crocodile and the bottlenose dolphin. Safety zones for these species were established around the blast area (Jordan et al. 2007). Pressure data were collected with the intention of demonstrating that pressures did not exceed safe levels previously established and that confined blasting produced much smaller kill radii than “open water” safety models predicted. Blast monitoring was conducted from 6 to 12 August 2005.

Explosives shot in open water will produce both higher amplitude and higher frequency shock waves than contained detonations. Thus, the use of blasting in rock removal during channel or harbor deepening projects should result in reduced pressures and lower aquatic organism mortality than the same explosive charge weight detonated in open water (Nedwell and Thandavamoorthy 1992; Marine Technology Directorate Ltd. 1996). This is important because most mortality models used to compute aquatic organism mortality by natural resource agencies were developed using open-water shot data that will overestimate demolition or embedded shots. However, published field verification of the pressure reductions during production blasting is nonexistent. The deepening project provided the opportunity to conduct pressure measurements during rock removal and compare those data with computed peak pressures for open-water explosions.

MATERIALS & METHODS

Types of Explosives and Initiation

The blasting agent used for the rock removal project was Pourvex PHD, a water slurry, manufactured by ETI Canada Ltd. The slurry has a specific gravity of 1.34, a detonation velocity of 20,000 feet/second (fps) [6,100 meters/second (mps)], and it is not cap sensitive, requiring a booster initiated by a blasting cap. The placed charges were 5.6 pounds (lb) per ft [8.3 kilograms(kg)/m] of the 4.5-inch (11-cm) diameter shot holes. The charges monitored during the study varied from a low of 17 lb (7.7 kg) to a maximum of 134 lb (60.8 kg) of charge weight per delay, depending on the height of rock relative to the dredge depth, decking, and the pattern's layout. Two High Detonation Pressure (HDP) boosters, distributed by ETI Canada Ltd., were used in each shot hole. Each booster had a weight of 1.0 lb (0.45 kg), a specific gravity of 1.60, and a detonation velocity of 26,000 fps (7,900 m/s).

The initiation system deployed a Detaline system dual path, precision delay, non-electric initiation cord and components. The system utilizes a fine, extruded detonating cord with a PETN explosive core of 2.4 grains per ft (0.51 g/m). The timing and delay sequence to the shot holes were achieved with "Detaslide Delays" detonators. The detonators were used in each booster and were connected via Detaline to "Detaline Surface Delays." The surface delays were connected to a dual trunk of Detaline. All the shot holes were drilled, loaded and connected to the dual trunk line. The shot was initiated using a "Noiseless Lead-in-Line." An instantaneous detonator was attached to a length of hollow shock tube that contains explosive dust. The entire shot was initiated by a blasting cap, which was fired into the shock tube connected to the trunk line delay system to the individual shot holes. By using a non-electric initiating system the shot was safely initiated and connected without concern for radio silence. Radios can initiate primary electrical initiation systems.

Shot Patterns

A typical section of material to be removed consisted of a foot of silty clay overburden, 6 to 8 ft (1.8 to 2.4 m) of the competent Miami Oolitic Limestone, over a low strength marl. The take elevation was -48 ft (-15 m) Elevation (EL), tidally corrected.

The August 2005 work was the closing removal near the port's south pier face. A planned pattern deployment positioned the drilling barges by surveying. Rock above the pay grade was drilled and shot. When rock was not encountered on the pattern above the pay grade, there was no need to place any blasting agent. This caused the shot pattern to be variable in size. The number of holes per row (termed ranges) and the number of ranges varied with the remaining high-rock surface topography. The spacing of shot holes along the ranges and between the ranges varied.

Stemming was used to confine the charge in each 4.5-in (11-cm) diameter shot holes to reduce blast pressures by restricting riffling into the water channel above the shot hole. The stemming was 5/8 to 3/4 inch (16 to 19 mm) particle size, crushed limestone. The stemming length was variable; the minimum stemming length was 3.5 ft (1.1 m) in the Miami Oolitic Limestone.

Pressure Recording and Analysis

The pressure transducer system consists of the arrayed transducers, cabling, timing, analog to digital conversion, and storage. The raw transducer voltage data and the previously acquired transducers' calibration allow calculation of the pressures at the location of the transducer.

There were two systems recording the pressures of Miami Harbor Rock Removal. The two deployed systems allowed the recordings to be more versatile to meet the needs of recording. One system was purchased by Contract Drilling and Blasting (CDB) and the second system was configured by St. Louis District (SLD), Corps of Engineers. Both systems used PCB Piezotronics transducers and constant-current source. The CDB system had a deck of analog to digital conversion and storage cards. The SLD system used a digital recording oscilloscope to accomplish the conversion and storage.

The transducers were suspended below buoys or off the side of a barge and referenced in position by surveying to the blast-hole pattern. CDB used three tranducers suspended by rope from a buoyed line at three regular positions 50-ft (15-m) apart. The CDB transducers were located approximately 5 ft (1.5 m) off the bottom (b), mid-water column (m) of about 20-ft (6-m) depth, and 5 ft (1.5 m) below the surface (t – top). The CDB m and t positions were taped to the rope, only the b transducer was free. The CDB system was capable of recording nine transducers and was triggered by a blasting cap at the start of the shot. The SLD system used four transducers and was triggered by exceeding a threshold pressure of the detonation cord leading to the loaded holes. The SLD transducers each were freely suspended a short distance apart hanging by the transducer cable with a weight attached below the transducer.

All the transducer data was corrected for the individual transducer's calibration. Pretest calibration was conducted by PCB Piezotronics. The pressure time history could then be analyzed. The pressures should be accurate to $\pm$ 5% to 8%. While the pressure data may be given with three digits, it is only accurate to one and a half significant digits.

Pressure Data for the Closest Holes

Pressure data by transducer are provided for four shots in Table 1. AP36, AP37 and AP38 are pattern shots with charge weights of 17, 32 and 32 lb, respectively. [Metric conversions are included when there are not multiple comparisons.] AP38 booster is the shot of an open-water (1 lb, 0.45 kg) booster shot at 20-ft (6-m) depth (midwater column). As may be noted in the table, AP36 had one shot that was very poorly confined. The reason for the lack of confinement is unknown, perhaps poor rock conditions or poor stemming placement. It is not known precisely which hole was poorly confined; it was likely the first or second hole furthest from the transducers.

Many holes were well confined by stemming and the strength of the rock in all three shots. A plume rose at the very poorly confined hole of AP36. Cavitation hats, high negative pressures at the water surface, occurred above holes that had less than full confinement. The closest holes, the last in time, for shots AP37 and AP38 may be used to develop an equation for well confined holes in this locale. Other rock locations are likely to have better confinement, but other rock stratigraphies would need to be investigated. Note in Table 1 the last column shows when the closest hole, best located and unambiguous for the data, has the maximum (1^{st}) or second maximum (2^{nd}) value of the entire record.

Table 1. Pressures and Parameters for Three Confined Shots and an Open-Water Charge.

					Entire Transducer Record				Closest Hole Values		
Blast	Max Charge Wt/Dlay (lb)	Transdr Des'gntn	Closest Lateral Apro'ch (ft)	Appro Dist (ft)	Max Pres (psi)	2^{nd} Max Pres (psi)	Min Pres (psi)	2^{nd} Min Pres (psi)	Max Pres (psi)	Min Pres (psi)	Sc Dis (fpp1/3
AP36	17	1, 50b	50	54	saturt'd	odd					
8		2, 50m	50	62	saturt'd	odd					
confined		3, 50t	50	72	saturt'd	odd					
holes		4, 100b	100	104	263	84.4	-30.7	-24.2	obscr'd	obscr'd	
less		5, 100m	100	112	207	50.7	-29.1	-26.9	obscr'd	obscr'd	
confined		6, 100t	100	122	saturt'd	odd					
		7, 150b	149	153	saturt'd	odd					
		8, 150m	149	161	201	36.2	-48.7	-28.1	obscr'd	obscr'd	
		9, 150t	149	171	saturt'd	odd					
		10, 100b	100	104	289	67.5	-30.0	-27.6	obscr'd	obscr'd	
		11,100m	100	112	274	58.3	-45.5	-29.3	obscr'd	obscr'd	
		12, 100t	100	122	275	69.5	-103.4	-54.7	obscr'd	obscr'd	
		13,100m	108	120	264	102	-70.3	-37.2	obscr'd	obscr'd	
AP37	32	1, 50b	50	54	29.7	9.6	-14.4	-11.8	8.0	-11.8	17
12		2, 50m	50	62	42.8	12.3	-22.9	-15.8	12.3	-10.9	20
confined		3, 50t	50	72	32.6	16.5	-20.4	-16.2	16.5	-20.4	23
holes		4, 100b	123	127	33.9	13.2	-9.4	-6.9	5.0	-6.6	40
		5, 100m	123	136	25.0	13.9	-9.1	-7.5	5.1	-5.0	43
		6, 100t	123	145	30.4	8.2	-17.7	-9.8	6.3	-5.7	46
		7, 150b	198	202	28.6	7.6	-5.9	-4.9	4.6	-5.9	64
		8, 150m	198	210	17.9	8.4	-6.8	-5.4	3.0	-4.8	66
		9, 150t	198	220	odd	displaced					
		10, Wb	159	163	41.6	9.4	-20.0	-7.0	2.6	-3.9	51
		11, Wm	156	168	23.9	13.4	-8.8	-6.3	3.2	-3.0	53
		12, Eb	164	168	18.3	5.6	-7.4	-4.9	2.1	-2.3	53
		13, Em	166	179	17.2	5.0	-13.1	-4.1	2.3	-2.2	56
AP38	1	1, Wb	85	87	46.3	16.9	-12.1	-5.2			85
booster		2, Wm	88	88	51.4	20.5	-34.7	-6.3			88
1 open		3, Eb	62	64	61.2	15.1	-11.6	-8.4			62
water		4, Em	64	64	66.9	11.8	-20.8	-11.1			64
AP38	32	1, 50b	50	54	89.7	44.7	-24.3	-15.7	31.3	-24.3	17
12		2, 50m	50	62	57.2	45.7	-26.7	-11.7	30.5	-26.7	19
confined		3, 50t	50	72	29.3	24.1	-21.4	-16.5	22.7	-21.4	23
holes		4, 100b	94	98	odd	cyclic					
		5, 100m	94	106	odd	cyclic					
		6, 100t	94	116	26.6	12.0	-13.6	-12.3	5.7	-13.6	37
		7, 150b	150	154	30.8	26.7	-16.2	-7.8	4.7	-16.2	48
		8, 150m	150	162	19.0	15.6	-12.5	-10.2	5.4	-12.5	51

	9, 150t	150	172	10.0	9.7	-10.0	-8.4	4.9	-10.0	54
	10, Wb	157	161	45.0	24.1	-14.0	-11.2	45.0	-11.2	51
	11, Wm	160	172	19.8	17.7	-19.2	-8.9	19.8	-8.9	54
	12, Eb	170	174	12.1	10.6	-9.9	-6.5	10.6	-9.9	55
	13, Em	168	180	11.3	10.4	-19.1	-7.2	11.3	-19.1	57

Des'gntn –Designation; Appro – Approximate; Sc Dist – Scaled Distance; fpp1/3 – ft/lb^1/3; saturt'd – saturated; obscr'd – obscured by a continuing cycle.

This Miami Harbor location shows that many holes were not as completely confined as desirable. Yet, every hole recorded in these confined shots had lower pressures than would have been recorded as an open-water shot of the same charge weight.

The closest hole of AP37 had no cavitation hat and clearly was well confined when shot. Figure 1.a shows the closest holes of AP37 in comparison the higher pressure at larger scaled distance for the open-water shot of a 1-lb (0.45-kg) booster (AP38 Booster). Note that the smaller charge (1 lb, 0.45 kg) from the further open-water shot produces greater pressures.

Sufficient data were available to produce a regression curve from the data of Figure 1.a. A modification of the regression curve to exceed all twelve points was determined. Following Cole's (1948) equation format, the maximum pressure, p_C, from the closest confined charge of the AP37 data is:

$$p_C \text{ (psi)} = 1{,}780\ SD_C^{\ -1.23},$$

where

SD_C = the confined scaled distance and $SD_C = d / (w_C^{\ 1/3})$,

D = the distance from the single confined blast to the point of pressure value, p_C, and

w_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

The equation's values are plotted in Figure 1.a for values of confined scale distance.

The closest hole of AP38 was not as well confined. Figure 1.b includes all the data from the shots of AP37 and AP38 (all useable data) for the closest holes to the transducers. There is a single point that is an extreme outlier of AP38, SD_C of 50.8 feet per cube root of pounds (fpp1/3) of charge weight per delay and 45 psi [310 kiloPascals (kPa)]. A regression fit of the 22 points was adjusted until all the points, including the outlier, were beneath the curve. This conservative fit of the data is:

$$p_C \text{ (psi)} = 5{,}640\ SD_C^{\ -1.23}\ . \qquad [1]$$

This latter Equation 1 should give an upper bound to well confined charges for Miami Harbor. The Equation 1's values are plotted in Figure 1.b for values of confined scale distance.

Calculation of Mortality Radius

Cole's equation for open-water pressures was manipulated using Hubbs and Rechnitzer's (1952) lower bound of lethal pressure value of 40 psi (280 kPa). This equation was previously used by Hempen et al. (2005). The mortality radius for single, open-water shots, MR_{OW}, is:

$$MR_{OW} \text{ (feet)} = 260\ w_{OW}^{\ 1/3}, \qquad [2]$$

where

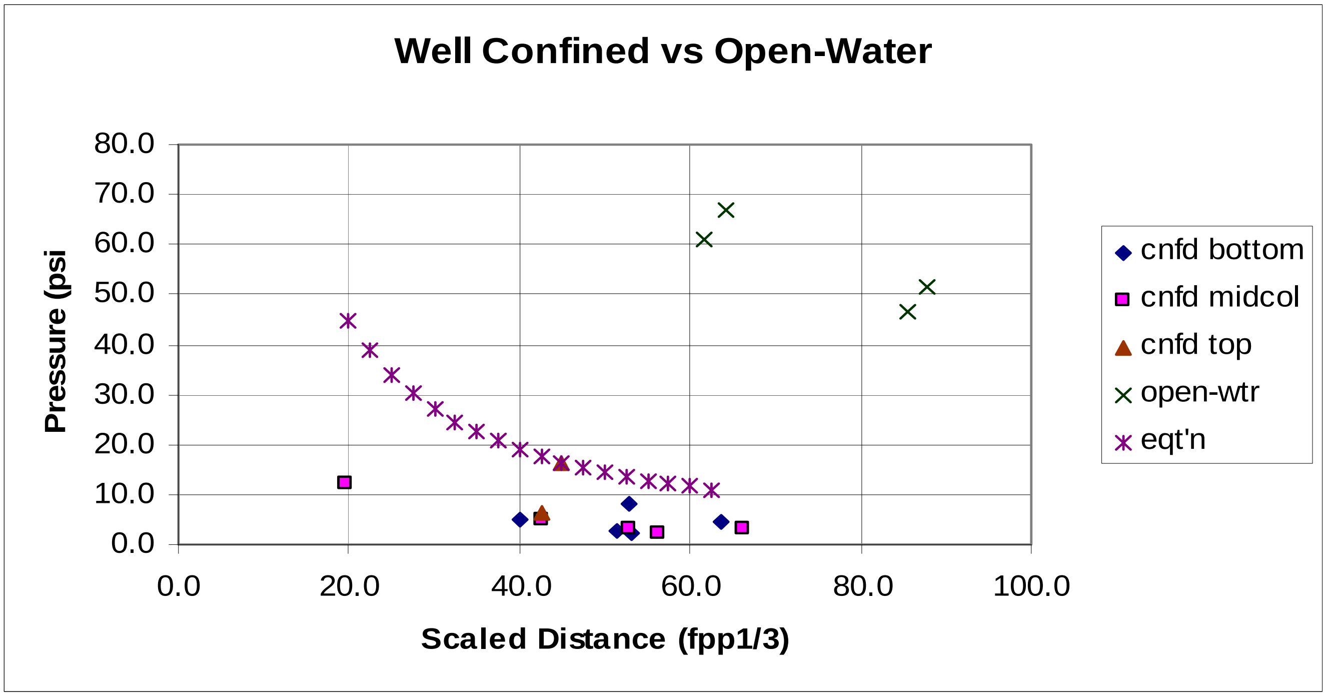
w_{OW} = the maximum charge weight (in pounds) per delay of a single, open-water blast.

Equation 1 was developed as a conservative estimate of pressure from the closest confined holes at Miami Harbor. The mortality radius for confined shots may be resolved from the confined pressure Equation 1 and using the low lethal pressure of 40 psi. The mortality radius for single, confined shots, MR_C, is:

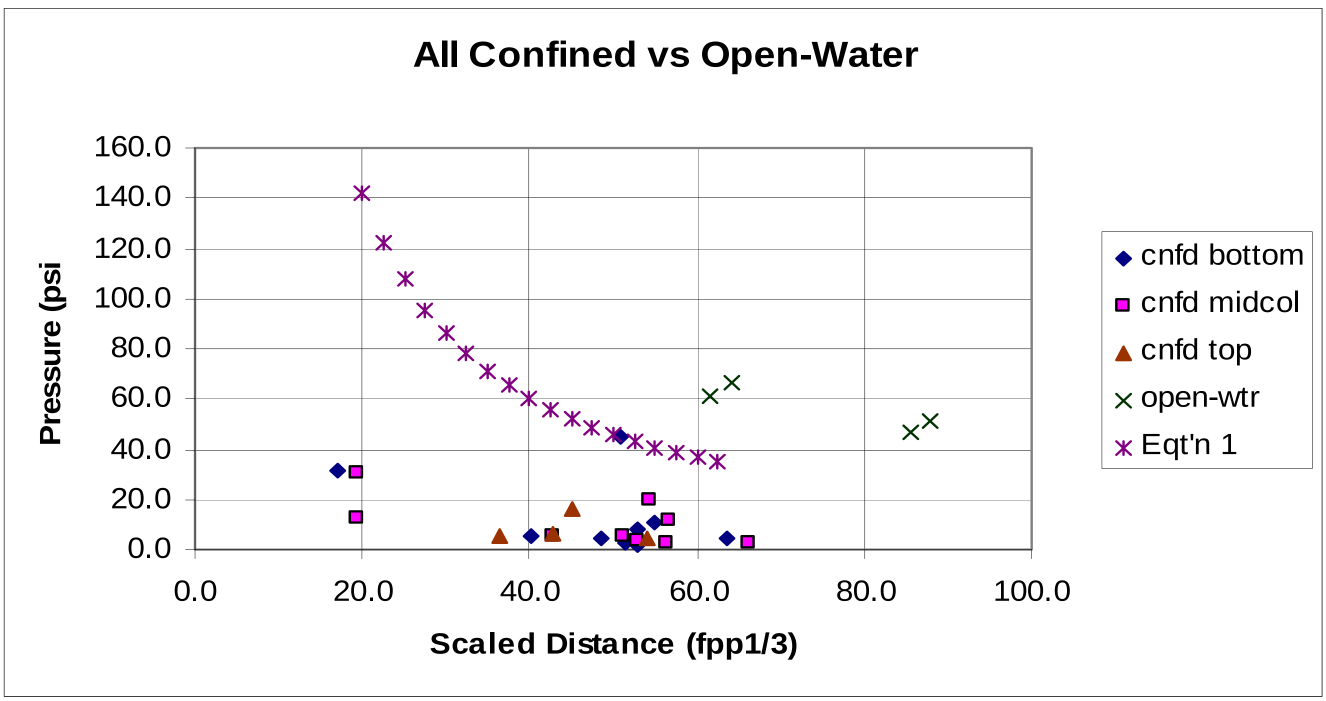
$$MR_C \text{ (feet)} = 56\ w_C^{\ 1/3}, \qquad [3]$$

where

w_C = the maximum charge weight (in pounds) per delay of a single, confined blast.



a. Graph of the Well Confined Holes of AP37 compared to the Open-water Booster shot.



b. Graph of Shots AP37 and AP38 Confined Holes compared to the Open-water Booster shot.

Figure 1. Graphs of the Closest Hole Parameters for the Transducer Locations.

If the equation for well confined shots had been used of AP37 and Figure 1.a, the coefficient would have been only 22. The coefficient of 56 in Equation 3 compares favorably with the mortality equation of Kill Van Kull (New York Harbor) Deepening Project, noted herein as KVK, of 80 (Hempen, et al. 2005). The KVK work had less data and its data was less well defined.

RESULTS

The pressures of the rock removal shooting have been well recorded. Quality, maximum pressures are provided in Table 1. The maximum pressures and their waveforms show very short duration peaks that may be related to the complex shot pattern and pathways of the waves. Impulse parameters of the better records were developed, but are not the subject of this paper**.**

DISCUSSION

The maximum pressures from the confined shooting were significantly lower than much smaller charges shot in open water. For Example, the kill radius of the 1-lb (0.45-kg) booster shot in open water, based on the results of Equation 2, was 260 ft (80 m). The kill radius would have only been 56 ft (17 m), as a conservative assessment, for a 1-lb charge that was confined by stemming within rock at Miami Harbor. The same charge may only have a kill radius of 22 ft (6.7 m) or smaller when confined within competent rock that was properly stemmed for confinement. The kill radii for the confined shots recorded at Miami Harbor of 17, 32, 67, and 134 lb/delay may have been calculated as 140, 180, 230 and 290 ft, respectively. Radiation of the wave energy into rock reduced the available energy reaching the water column. The pressures entering the water column were well below those pressures that typically propagate away from open-water (unconfined by solid media that may radiate the energy away with less harm) charges relative to charge weight per delay.

These study results corroborate previous laboratory studies and field studies that found reductions in peak pressure from confined shots. Nedwell and Thandavamoorthy (1992) compared the pressure time histories from the detonation of small explosive charges (1.8 g ICI Star detonator No. 8) in both free water and embedded in concrete blocks under laboratory conditions. They found that the peak pressure of the water-borne shock wave following the detonation of an explosive charge embedded in a borehole was about 6% (94% reduction) of that occurring for the same charge at the same distance, when it was freely suspended in water. Hempen et al. (2005) evaluated pressure reductions during channel deepening for the KVK. They compared pressures from four confined shots with computed open-water pressures and found that the confined pressures were only 19 to 41% (81 to 59% reductions) of open-water pressures. The mortality radius was 30% of the open-water shot and the mortality area of the confined shot would be only 9% of the mortality area for the open-water shot. Note that for the KVK, the largest calculated fish mortality was 350 ft (105 m) for a shot pattern containing 28 boreholes, with an 87 lb being the largest charge per delay shot. The mortality radius for moderately confined holes of Miami Harbor was 22% of the open-water shot and the mortality area of the confined shot would be only 5% of the mortality area for the open-water shot.

The maximum pressures recorded were related to the maximum charge weight per delay and clearly were unrelated to the total weight of blasting agents (e.g., sum of all the explosive weights in the bore holes detonated in a shot) that were detonated. The shot pressures were relatively uniform, while the shots varied significantly in total charge weight. Total charge weights for the blasting cap, 1-lb booster, and three pattern shots were: 1 cap, 1 lb, 136 lb, 408 lb and 408 lb. [Data for the blasting cap was recorded but is not reported within this paper to save space.] Maximum recorded pressures (without correcting to a common distance) in order of total charge weight were: 41 psi, 67 psi, 290 psi, 43 psi, and 90 psi. It is easy to note the largest pressure of 290 psi {2,000 kPa [136 lb (61.7 kg), total charge weight; 17 lb (7.7 kg), charge weight per delay]} was for the poorly confined hole of AP36. The range of total charge weights exceeds a multiple of 1,000, while the maximum pressures clearly do not correlate to total charge weight. Parameters other than total charge weight control the maximum pressure and impulse. Hempen et al. (2005) found similar results for the KVK. KVK Shots 014 and 010 produced comparable peak pressures. Shot 014, had only two shot holes, with a maximum charge weight per delay of 72 lb {33 kg (total charge weight of 98 lb (44 kg)]}, while shot 010 had 25 shot holes, with a maximum charge weight per delay of 73 lb {33 kg [total charge weight over 1,500 lb (680 kg)]}. These results support the suggestion of Munday et al. (1986) that the use of delays effectively reduces each detonation to a series of small explosions. Resulting blast overpressure levels are directly related to the size of the charge in each delay, rather than the summation of charge weights detonated in all holes. The use of delays has been suggested as a potential mitigation measure to reduce pressure exposure to aquatic organisms (Keevin 1998).

There are a number of physical attributes of the pressure waveform from the confined shots measured in this study that suggest that mortality would be lower than indicated by the peak-pressure measurements. The rapid oscillation from a high, brief overpressure and a moderate, but longer, underpressure associated with detonation of high explosives in the water column is most probably responsible for organ damage and mortality in fish. This oscillation in waveform is responsible for the rapid contraction and overextension of the swimbladder resulting in internal damage and mortality (Wiley et al. 1981). It has also been suggested that the negative phase (relative to ambient) of the pressure wave is responsible for organ damage (particularly the swimbladder) and mortality (Anonymous 1948; Hubbs and Rechnitzer 1952 and Wiley et al. 1981). During the current study, the abrupt compressing pressures, usually associated with the detonation of high explosives, were reduced in amplitude and negative pressures were small relative to the background noise.

Hubbs and Rechnitzer (1952) determined that the lethal threshold peak pressure for a variety of marine fish species exposed to dynamite blasts varied from 40 psi (280 kPa) to 70 psi (480 kPa). The more conservative pressure of 40 psi from Hubbs and Rechnitzer (1952) was used to develop Equations 2 and 3, even though their range extends much further than for 70 psi. Keevin (1995) found no mortality or internal organ damage to bluegill exposed to a high explosive at pressures at or below 60 psi (420 kPa). The 40-psi value is also conservative because the waveform of the mortality value was established from an open-water testing program and not from similar confined shots that did not have clear extension (negative pressure) phases for measurable impulse and energy measures. There is some evidence, as previously stated, that confined shots may not have mortal pressures as low as those for open-water shots, but this conclusion requires further testing.

This study clearly demonstrates that explosives shot in open water will produce both higher amplitude and more rapidly oscillating shock waves than rock removal shots. Thus, the use of blasting in rock removal will result in lower aquatic organism mortality than the same explosive weight detonated in open water. This conclusion is important because the majority of aquatic organism mortality models were developed using open water shot data that will overestimate rock removal shot mortality. Safety zones calculated using open water mortality models are used to establish watch plans and optimal observer locations to protect aquatic organisms (Jordan et al. 2007). If the observation area becomes too large, based on the use of open-water shot pressures, then there is also the possibility that the level of intended species protection is diminished. It is much easier to monitor a small area than a very large area. As the dimensions of a watch zone unnecessarily increase, there is undoubtedly a safety radius that would also preclude blasting because of the high cost of monitoring, long blasting delays due to aquatic organisms wandering into the enlarged blast zone, and the reduced efficiency of being able to protect the organisms of concern.

ACKNOWLEDGEMENTS

The pressure-recording operation could not have been conducted without the Contract Drilling and Blasting (CDB) and Great Lakes Dredge and Dock Company (Great Lakes), the Port of Miami, and the involvement of the Army Corps of Engineers, Jackson Ville District's Construction Office for the Miami Harbor Contract. Operationally, the work would not have been possible without the aid of the main contractor, Great Lakes, and the blasting subcontractor, CDB. Both contractors provided important assistance to accomplish the pressure recording. CDB also provided valuable assistance in configuring the transducer arrays and providing support for the water-based recording. Great Lakes provided Global Positioning System (GPS) locations of the transducer arrays and maps of the shot positions and transducer locations. CDB provided data on the explosives placed and ground vibration recordings. We acknowledge the assistance of Emery Gray, CDB. It is with saddened hearts to note that Emery passed away in November of 2006. We dedicate this paper to Emery Gray's memory.

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APPENDIX 4

Port of Miami Project-Protecting Marine Species During Underwater Blasting

Port of Miami Project – Protecting Marine Species During Underwater Blasting

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Abstract - The Port of Miami, Miami-Dade County, Florida (Port) is the largest container port in the State of Florida. However, it is located in the center of a diverse ecosystem. Biscayne Bay surrounds the Port and portions of the bay have been designated as a National Park, a Florida Aquatic Preserve and a state Critical Wildlife Area. The bay is home to many protected, threatened and endangered species including the Florida manatee, five sea turtle species, American crocodile and bottlenose dolphin, in addition to important recreational and commercial fish species.

In 1990, Congress authorized the deepening and expansion of the Port including deepening of the Dodge Lummus Island Turning Basin and Fisherman's Channel to -42 feet. The Port previously attempted to complete the project without underwater blasting. The contractor and subsequent surety company were unable to successfully complete the authorized work primarily due to the limestone bedrock that was resistant to dredging. In 2000, the Port approached the Jacksonville District, U.S. Army Corps of Engineers (District) to complete this project. The District determined that blasting would be required as a construction technique and that Miami Harbor is occupied by a number of species that are protected under the Endangered Species Act (ESA) including the manatee, two species of sea turtles and the crocodile. As a result the District initiated consultation with the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) under Section 7 of the ESA. The District also determined that bottlenose dolphins, a species protected under the Marine Mammal Protection Act (MMPA), had been documented transiting through the Port and could also be affected by the proposed blasting. The District submitted an application for an Incidental Harassment Authorization under the MMPA in June 2002, which was issued in 2004 and renewed in April 2005. Construction blasting began in June 2005 and was completed in August 2005. A key determination made by NMFS and the USFWS was that protected marine species were unlikely to be seriously harmed by the detonations due to the District's conservative monitoring and mitigation measures aimed to ensure that protected marine species would not be within a pre-determined safety zone when the detonations occurred. This paper reviews the results from protected species watch program; an overview of acoustic and pressure measurement data collected during construction; and potential implications for future work using blasting as a construction technique in Florida or elsewhere.

Introduction - The Port of Miami (Port), located on the southeast coast of Florida, is in the top 10 cargo container ports in the United States and is the largest container port in Florida. The Port carries the dual distinction of “Cruise Capital of the World” and “Cargo Gateway of the Americas.” In 2005, approximately 3.5 million passengers and more than one million tons of cargo transited through the Port of Miami from around the world (Port of Miami website, accessed September 2006). The Port is also located in the center of a unique and diverse ecosystem. Biscayne Bay surrounds the Port and portions of the Bay have been designated as a National Park, a Florida Aquatic Preserve, an Outstanding Florida Water, and a state Critical Wildlife Area (Figure 1).

Figure 1 – An aerial photograph of the Port of Miami, centrally located in Biscayne Bay

Biscayne Bay is home to many protected, threatened and endangered species including the Florida manatee (*Trichechus manatus*), five sea turtle species (*Family Chelonidae*), American crocodile (*Crocodylus acutus*) smalltooth sawfish (*Pristis pectinata*) and bottlenose dolphin (*Tursiops truncatus)*, in addition to numerous important recreational and commercial fish species including, but not limited to various life stages of penaeid shrimp complex, red drum, reef fish, stone crab, spiny lobster, migratory/pelagic fish, and snapper/grouper complex. Terrestrial and marine habitats surrounding the Port include beaches, mangroves, seagrass beds, and hardbottom and reef communities. Due to the ecologically diverse and significant marine resources within the vicinity of the Port, any construction, maintenance, or operational activities are of primary interest to the Federal, State, and local natural resource and regulatory agencies (agencies). In addition, Miami-Dade County has many active non-profit organizations (NGOs) whose focus is on protecting natural resource and coastal development issues.

In 1990, in response to the need for continued growth of the Port to meet the demands of the passenger and commercial shipping industries, Congress authorized the deepening and expansion of the Port to 42 feet (12.8 m). Phase I, in which the Port deepened the entrance channel and Fisher Island turning basin, was completed in 1993. Phase II, a $40 million project to address the South Harbor, was initiated in the mid 1990s and was unable to be completed due to the hardness of the rock and the contractor's equipment. The Port's permits at the time did not allow them to utilize blasting as a construction technique. In 2000, the Port approached the Jacksonville District, U.S. Army Corps of Engineers (District) to complete the construction. The Corps' engineers determined that due to the hardness of the limestone rock, blasting would be required to pre-treat the rock before dredging. Construction began in June 2005 and was completed in July 2006. This work involved 38 days of blasting between June and August of 2005, in the Dodge-Lummus Island Turning basin and Fisherman's Channel on the south side of the Port.

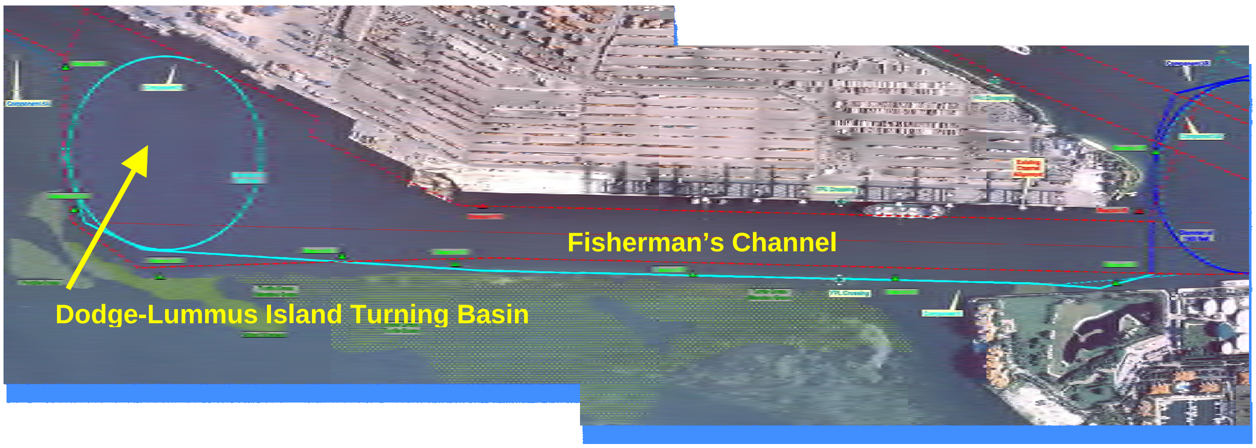

Figure 2 – Close up aerial photograph of the Dodge-Lummus Island Turning Basin and Fisherman's Channel

One of the major concerns associated with the project was the potential effects of blasting on protected marine species inhabiting Biscayne Bay. Blasting effects on marine animals associated with open water blasts (i.e., military ordinance and oil rig removal operations) are well documented (Finneran, *et al*., 2000) and can range from harassment to direct injury and mortality. Dolphins are a highly auditory species dependent upon vocalization and their sensitive and well-developed perception of sound for nearly all aspects of their behavior and survival. Temporary threshold shifts (TTS) in a dolphin's ability to perceive sound and direct injury to ear structures could have long-term negative consequences for individual dolphins as well as to group dynamics and behavior. TTS is well documented in the literature for dolphins (Ketten, 1996) as are some of the physical injuries to auditory structures (Ketten, 1996; Keevin and Hempen, 1997). Both dolphins and manatees are also highly susceptible to lethal and sub-lethal injuries by the reaction of air cavities within the body to the pressure waves produced from the blast. In particular, organs such as the lungs and intestines can be severely compromised even though outward injury may not noticeable. Very little information is available on the effects of blasting on marine reptile species, including sea turtles and crocodile (Keevin *et al*., 1999).

The focus of the proposed blasting work at the Port was to pre-treat bedrock prior to removal by a dredge utilizing confined blasting, meaning the shots would be "confined" in the rock. In confined blasting, the hole in which the explosive material is placed is capped with an inert material, such as crushed rock. This is referred to as "stemming the hole." Studies have shown that stemmed blasts have up to a 60-90% decrease in the strength of the pressure wave released, compared to open water blasts of the same charge weight (Nedwell and Thandavamoorthy, 1992; Hempen *et al*., 2005). However, unlike open water blasts, very little documentation exists on the effects that confined blasting can have on marine animals near the blast (Keevin *et al*., 1999).

Regulatory Issues - As previously stated, the District had determined that the waters surrounding the Port were home to many endangered and threatened species. As required by the Section 7 of the Endangered Species Act of 1973 (ESA), the District initiated consultation with the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) concerning the potential effect the deepening project could have on listed species under their purview. These consultations resulted in findings that the proposed blasting was likely to affect, but unlikely to adversely affect listed species in the project area (NOAA 2002, USFWS 2002).

The District also determined that a population of bottlenose dolphins, a species protected under the Marine Mammal Protection Act of 1972 (MMPA), had been documented transiting through the Port and could be affected by the proposed blasting. Under the MMPA, it is illegal to take marine mammals (in any manner) without a special authorization. The term "take" means to harass, hunt, capture, or kill or to attempt to harass, hunt, capture or kill any marine mammal. The District applied for and received an incidental harassment authorization (IHA) from NMFS in 2003 and renewed in 2005 with the knowledge that dolphins transit the project area and are likely to incur some incidental harassment as defined in the MMPA as a result of blasting activities (NOAA 2003, 2005a). When the IHA was issued, NMFS concluded that:

"NMFS has determined that the Corps' proposed action, including mitigation measures to protect marine mammals, should result, at worst, in the temporary modification in behavior by small numbers of bottlenose dolphins, including temporarily vacating the area to avoid the blasting activities and the potential for minor visual and acoustic disturbance from the detonations. This action is expected to have a negligible impact on the affected species or stocks of marine mammals. In addition, no take by injury and/or death is anticipated, and harassment takes will be at the lowest level practicable due to incorporation of the mitigation measures described" (NOAA 2005b).

The Mitigation Plan (Protected Species Watch Plan) - As part of the development of the protected-species protection and observation protocols, which were incorporated into the plans and specifications, the Corps worked with the agencies and NGOs to address concerns and potential impacts. One challenge was the misconceptions and misinformation brought to the protocol development by the agencies, since none had any previous experience with confined underwater blasting as a construction technique. As a result, in an effort to educate the agencies and the public, the Corps and Port hosted a series of blasting "workshops" to provide information about blasting, and more specifically, confined blasting.

A danger zone radius was calculated to determine the maximum distance from the blast at which harassment or injury to protected marine species is likely to occur. This danger zone was determined by the amount of explosives used within each delay (which can contain multiple boreholes). These calculations are based on impacts to terrestrial animals in water when exposed to a detonation suspended in the water column (unconfined blast) as researched by the U.S. Navy in the 1970s (Yelverton *et al*., 1973; Richmond *et al.*, 1973). The reduction of impact by confining the shots would more than compensate for the presumed higher sensitivity of marine species. The District believed that this danger zone radius was a conservative, but prudent, approach to the protection of marine wildlife species. The zone calculations were done using a tiered approach based on level of impact and mitigative procedures. These zone calculations were included as part of the specifications package.

The calculations are as follows:

1) Danger Zone: The radius whose outer limit represents the minimum distance for no expected mortality. The danger zone (ft) = 260 [79.25 m] X the cube root of weight of explosives in lbs per delay.

2) The Safety zone (sometimes referred to as the exclusion zone) is a larger radius to insure species are beyond the minimum distance whereby harassment may occur, typically beyond the 180 dB isopleths. The safety zone (ft) = 520 [158.50 m] X cube root of weight of explosives in lbs per delay.

3) The Watch Zone is three times the radius of the Danger Zone to insure animals entering or traveling close to the safety zone are spotted and appropriate actions can be implemented before or as they enter any impact areas. Animals in the watch zone are closely monitored to insure they do not enter the safety zone.

The selected contractor, Great Lakes Dredge and Dock (GLDD) and their subcontractors, Contract Drilling and Blasting (CBD) and ECOES Consulting, Inc., submitted (as required per project specifications) an environmental protection plan that included a Protected Species Watch Plan to be utilized during blasting activities. This watch plan was forwarded to the resource agencies for review and in the cases of NMFS and USFWS, approval.

The blast plan that was developed between the Corps and GLDD maximized the efficiency of the rock removal while minimizing the impacts to the surrounding environment and species. All blasting was managed from the GLDD's Drill Barge, *Apache* (GLDD, 2005). The maximum poundage of explosives utilized for this project was not expected to exceed 375 lbs (107.10kg) per delay based on discussions with CDB's explosive's expert.

Using this explosive weight as the maximum expected during construction, the three radii would be:
Danger zone = 1,875 ft (572 m)
Safety zone = 3,750 ft (1,143 m)
Watch zone = 5,625 ft (1,715 m)
The Corps used these numbers as the worst case that would be encountered during construction.

Blasting began on 25 June and was completed on 12 August 2005 for a total of 38 days of blasting for 40 blasting events (3 days had 2 blasts). Explosive weights ranged from 17 lbs (7.7 kg) to 376 lbs (108 kg) per delay with the mean explosive weight per delay of 119lbs (54 kg) giving the mean zone distances of:

Danger zone =1,278 ft (390 m)
Safety/Exclusion zone = 2,556 ft (779 m)
Watch zone = 3,834 ft (1,169 m)

The 119-lb charge distances were used for conducting the watch program during all blasts unless the watch coordinator was informed that the blast weight was over 120lbs (54 kg) (Figure 3).

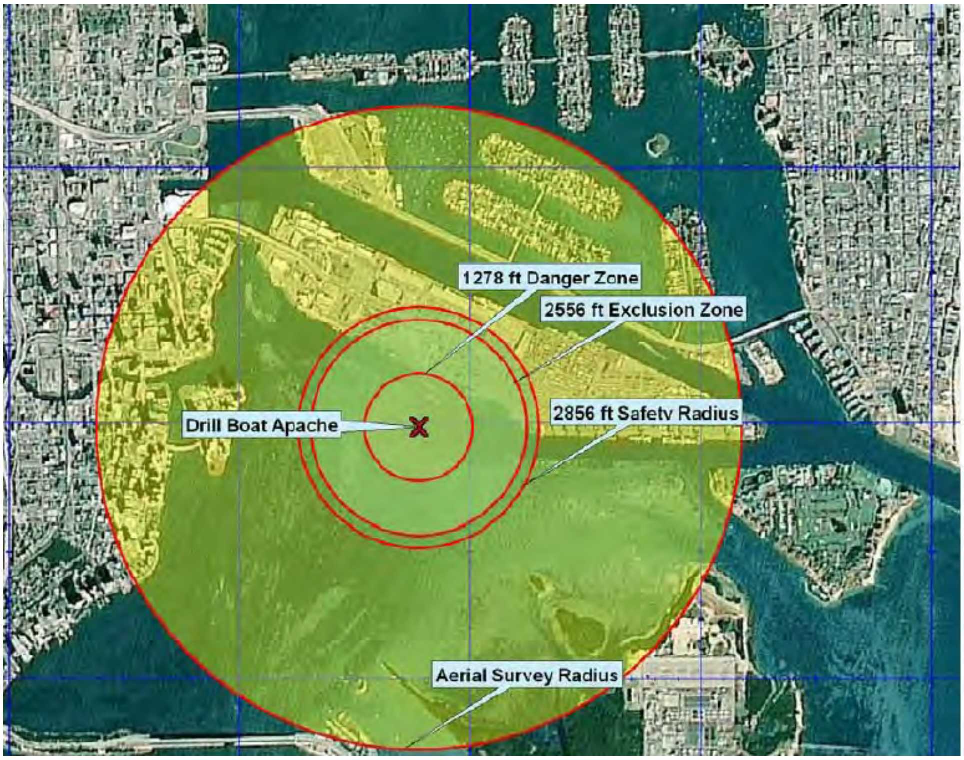

Figure 3 – Sample zone layout using the mean weight of explosives of 119lbs (53.98 kg).

A watch plan was formulated based on the required safety zones and optimal observation locations. The watch plan consisted of six (6) observers which included at least one (1) aerial observer, two (2) boat-based observers, and two (2) observers stationed on the drill barge. The 6th observer was placed in the most optimal observation location (boat, barge or aircraft) on a day by day basis depending on the location of the blast and the placement of dredging equipment. This process helped to insure complete coverage of the three zones as well as any critical areas. The watch began at least 1 hour prior to each blast and continued for one-half hour after each blast.

The aerial observer flew in a turbine engine helicopter (bell jet ranger) with doors removed. This provided maximum visibility of the watch and safety zone as well as exceptional maneuverability and the needed flexibility for continual surveillance without fuel stops or down time, minimization of delays due to weather or visibility and the ability to deliver post-blast assistance. Boat-based observers were placed on one of two vessels, both of which had attached platforms that place the observer's eyes at least 10 feet (3 m) above the water surface enabling optimal visibility of the water from the vessels (Figure 5). The boat observers covered the safety zone where waters were deep enough to safely operate the boats without any impacts to seagrass resources. The shallow grass beds south of the project site relegated the observer boats mainly to the channel east and west of the blast zone (Figure 4). The pontoon boat was able to move up the small pipe channel to the south of the site and in some of the deeper portions of the grass beds. At no time were any of the observer boats allowed in shallow areas where props could potentially impact the fragile seagrass.

The restricted access of the boats did not adversely impact the watch program since the visibility through the water column in the shallow areas was excellent from the air and under normal conditions; the bottom was visible to the helicopter observer. Therefore, the important areas for boat coverage were within the channel where animals were not as easily tracked from the air and thus boats could provide additional coverage. The only time this restrictive area became a concern was when the dredge *Texas*

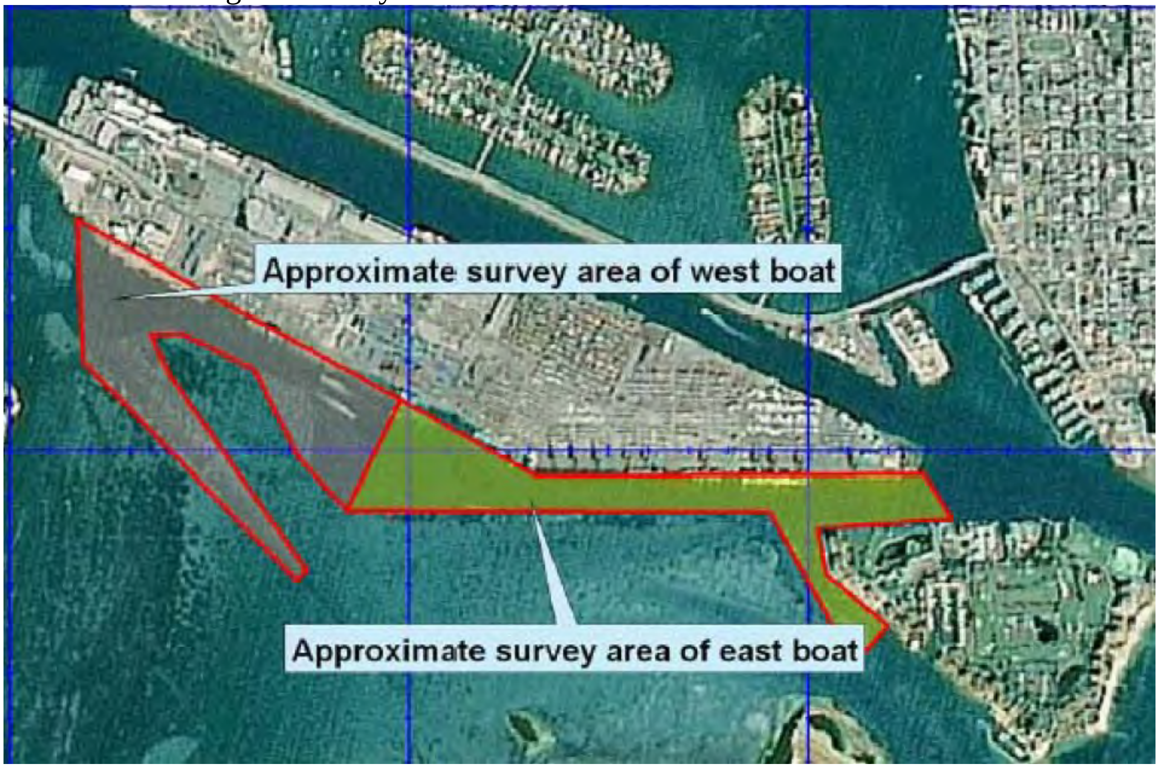

Figure 4 – Aerial photograph of the approximate survey area for each of the surface boats.

Figure 5 – Photographs of the two observer vessels, note the observation towers.

was operating and the tide was either flooding or switching from flood to ebb. At these times, apparent turbidity in the water was high and visibility through the water column was reduced so that animals were not seen below the surface as they would be under normal conditions in this area. However, animals surfacing in these conditions were still routinely spotted from the air and from the boats, thus the overall observer program was not compromised, only the degree to which animals were tracked below the surface. Adjustments to the program were made accordingly so that all protected species were confirmed out of the safety zone prior to T-minus 5 minutes, just as they would have been under normal visual conditions. It is important to note that the waters within the project area are exceptional for observation so that the decreased visibility below the surface during turbid conditions made the waters more typical of other manatee habitats and port facilities where observer programs are also effective.

All observers were equipped with marine-band VHF radios, maps of the blast zone, polarized sunglasses, and appropriate data sheets. In addition to this observation gear, all required personal protective equipment (hard hat, steel toed boots, life vest) was worn by observers at all times with the exception of the aerial observer.

Communications among observers and with the blaster was of critical importance to the success of the watch plan. The aerial observer was in contact with vessel and drill-barge based the observers and the drill barge with regular 15-minute radio checks throughout the watch period. Constant tracking of animals spotted by any observer was possible due to the amount and type of observer coverage and the excellent communications plan.

Watch hours were restricted to between two hours after sunrise and one hour before sunset. The watch began at least one hour prior to the scheduled blast and was continuous throughout the blast. Watch continued for at least 30 minutes post blast at which time any animals that were seen prior to the blast were visually re-located whenever possible and all observers in boats and in the aircraft assisted in cleaning up any blast debris.

If any protected species were spotted during the watch, the observer notified the aerial observer and/or the other observers via radio. The animal was located by the aerial observer to determine its range and bearing from the blast array. Initial locations and all subsequent re-acquisitions were plotted on maps. Animals within or approaching the safety zone were tracked by the aerial and boat based observers until they exited the safety zone. Anytime animals were spotted near the safety zone, the drill barge was alerted as to the animal's proximity and some indication of any potential delays it might cause.

If an animal was spotted inside the safety zone and not re-acquired, no blasting was authorized until at least 30 minutes had elapsed since the last sighting of that animal. If manatees were spotted near any of the operations, all crew boats, tugs and other vessels were notified to go to slow speed. The watch continued its countdown up until the T-minus five (5) minute point. At this time, the aerial observer confirmed that all animals were outside the safety zone and that all holds have expired prior to clearing the drill barge for the T-minus five (5) minute notice. A fish scare charge was fired at T-minus five (5) minutes and T-minus one (1) minute to minimize effects of the blast on fish that may be in the area of the blast array by scaring them from the blast area.

An actual delay in blasting only occurs when a protected species was located within the exclusion zone at the point where the blast countdown reaches the T-minus five (5) minutes. At that time, if an animal is in or near the safety zone, the countdown is put on hold until the zone is completely clear of protected species and all 30-minute sighting holds have expired. Animal movements into the safety zone prior to that point are monitored closely but do not necessarily stop the countdown. The exception to this would be stationary animals that do not appear to be moving out of the area or animals that begin moving into the safety zone late in the countdown. For these cases, holds on the T-minus 15 minutes may be called for in order to keep the shipping channel open and minimize the impact on Port operations.

<u>Results</u> - During observations, the expected two species of marine mammals were spotted, manatees and bottlenose dolphin, as well as loggerhead turtles (*Caretta caretta*) and other unidentified sea turtles. A total of 186 individual animals were spotted, with approximately 60% of these observations being manatees. Protected species were spotted during watches for 36 of the blasts or 95% of the watches.

Dolphins were spotted inside the exclusion zone 12 times with a total of 30 individuals; turtles were spotted inside the exclusion six (6) times for a total of seven (7) individuals; and manatees were spotted inside the exclusion zone five (5) times with a total of 14 individuals. Not every sighting within the exclusion zone caused a delay in blasting and in fact, most sightings within the exclusion zone did not result in an actual hold in the countdown (Barkaszi, 2005).

Conclusion - Based on the monitoring data collected during the construction of the Miami Harbor Phase II project, the District and NMFS continue to believe that due to the conservative monitoring and mitigation requirements of the IHA and ESA consultations, protected marine species were unlikely to have been harmed by the blast detonations due to the size of the blasts, the stemming of the charges, the depth of the water and the required stand-off distances between the animals and the blast array. This project serves as an example of cooperation, management and action to prevent impacts to protected marine species during channel-deepening blasting. Other projects may use the success of this program to tailor their projects' needs to avoiding harm to both protected species and the native marine biota, as a whole.

Acknowledgements

The authors would like to acknowledge the assistance of Mr. Luis Rene Perez, Project Manager, Corps of Engineers; Ms. Becky Hope, Environmental Manager, Port of Miami; Mr. Emery Gray and the Staff of Contract Drilling and Blasting; Mr. Rick Elizando and Mr. Sam Morrison, Great Lakes Dredge and Dock; Mr. Mark Reid and the crew of the drillboat *Apache*; the observers of ECOES Consulting, Inc.; Dr. Tom Keevin and Dr. Greg Hempen, Corps of Engineers, St. Louis, District as well as numerous colleagues and friends for their review and comments on this document. Without their work, this effort would not have been successful.

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NAVIGATION STUDY FOR

JACKSONVILLE HARBOR, FLORIDA

DRAFT INTEGRATED GENERAL REEVALUATION REPORT II

AND

SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT

APPENDIX A

ATTACHMENT E

ENGINEERING – Hydrodynamic Modeling and Field Data Summary

Hydrodynamic Modeling and Data Summary

Introduction

This General Reevaluation Report (GRR) is being prepared to determine the feasibility of deepening and/or widening the federal navigation channel of the Jacksonville Harbor Federal Navigation Project. Project alternatives considered include: deepening of the Federal Channel over the lower 20, 14, 13.7, and 13.1 miles of the St Johns River, widening along the Trout River Cut Range, Short Cut Turn and Training Wall Reach areas, and additional turning basins.

In order to support project design and evaluate project impacts, a comprehensive approach including data mining to identify and gather available observed data, field data collection and a suite of hydrodynamic and transport models was implemented. This Attachment describes the approach for modeling, data mining and data obtained during the 2009 field data collection. Field data used in this feasibility study include data previously collected by the SJRWMD, USGS, NOAA, and NOS and the USACE 2009 field measurement study conducted for this project.

The USACE 2009 field measurements were obtained using underway shipboard and mounted instrument platforms that collected data associated with tidal flows, discharge from the St. Johns River, Intracoastal Waterway and major tributaries, water surface elevations, along-channel and cross-channel gradients in velocity, salinity, depth, temperature and suspended sediment concentration. This data not only provides a better understanding of the processes and their interactions that govern the characteristics of the St Johns River but are also used for model input, calibration and validation for a comprehensive hydrodynamic modeling task. The hydrodynamic modeling task included the Adaptive Hydraulics Model (AdH), a two-dimensional hydrodynamic and sediment transport model of the Federal Channel and St. Johns River Estuary system and the ADvanced CIRCulation Model (ADCIRC), a coastal circulation and storm surge model, and development of the SJRWMD Water Supply Impact Study (WSIS) Environmental Fluid Dynamics Computer Code (EFDC) and EFDC/CE-QUAL-ICM TMDL models for the Jacksonville Harbor GRR2 to assess the effect of the Harbor deepening project on salinity, water age and water quality. Coastal processes were investigated using the Coastal Modeling System (CMS) in the vicinity of the St Johns River entrance to evaluate shoaling due to littoral transport and to assess the potential impacts on the adjacent beaches due to channel deepening. The field data analysis and modeling results were used to design a deepened Federal Channel that will accommodate future vessel classes while minimizing impacts to the environment.

Background

The St Johns River flows south to north and is about 300 miles long. The total elevation drop from the headwaters to the Atlantic Ocean is less than 30 ft, with an average slope of about one inch per mile (NOS,1998). Most of the river is relatively shallow but the last 26 miles has an average depth of about 30 ft (Morris, 1995) due to the Jacksonville Harbor Navigation Channel. The main navigation channel is about 23 miles long and extends from the river mouth to near downtown Jacksonville (Figure 1.).

Existing project depths in the navigation channel include 34 ft between the Talleyrand Terminal and downtown, 40 ft from River Mile 0 to 20, and 42 ft seaward of River Mile 0.

The total drainage area of the St Johns River is about 9,340 square miles and the average discharge is about 6,500 cfs at the river mouth (Morris, 1995). The total discharge is normally greater than 50,000 cfs and can exceed about 200,000 cfs (NOS, 1998, Sucsy and Morris, 2002). Smaller rivers, creeks and tributaries feed into the St Johns River, increasing the river flow, and affecting the tidal signal. Tidal influences affect the river more than 100 miles upriver. The total flow in the river is about 80 to 90 % tide induced. The remaining 10 to 20% is attributed to wind, freshwater inflow from tributaries and rainfall, point sources such as treatment plants. River flow is seasonal, following the seasonal rainfall patterns, with higher flows occurring in the late summer to early fall and lower flows occurring in the winter. The average annual nontidal discharge at the river mouth is about 15,000 cfs (NOAA, 1995).

Wind and pressure associated with frontal passages and northeasters can cause subtidal water level fluctuations which are significant compared to the normally tide dominated flow. The more significant of these meteorological events cause flow reversals in tide dominated segments of the river.

Figure 1. Existing Jacksonville Harbor Project Features.

Methodology

The suite of modeling tools are organized to support the iterative decision making process comprised of developing an initial alternative project design, benefits, then evaluating alternative project impacts and costs, to ultimately arrive at an economically justified selected plan project design. The project design and impact considerations include the navigation channel features, such as deepening, widening, and turning basin that contribute to efficient and safe vessel operation (Table 1) and channel shoaling, coastal processes, waterlevels, salinity, and water quality.

Table 1. Project Considerations

PROJECT DESIGN	PROJECT IMPACTS
Deepening	Riverine Channel Shoaling rates
Turning Basins	Littoral Processes in the Coastal Ocean & Shoaling Rates
Wideners	Water Levels –tide, storm surge, sea level change
Vessel Handling	Flows in Adjacent Embayments
	Bank Erosion
	Salinity for Environmental Impacts
	Water Quality for Environmental Impacts

The criteria for selecting appropriate hydrodynamic models are also based on the objectives of the navigation study which are to optimize channel modifications and to assess project impacts. An important distinguishing characteristic of hydrodynamic models for the design purposes of this study is the model's ability to efficiently represent channel modifications. The existing main channel is 400' ft wide but can be as much as 1200' wide in sections, and the alternatives under consideration do include widening the channel at Mile Point, Trout River, SW Blount Island, East Mill Cove and at the Terminal Channel. In order to accurately represent these modifications in a hydrodynamic model the horizontal grid resolution must be on the order of 50 to 100 ft. This resolution is not required in areas away from the channels. Therefore the most computationally efficient model would be based on a variable resolution grid. The AdH unstructured triangular adaptive mesh make this model a good choice for resolving the existing channel geometry and alternative channel widening features.

In developing an integrated modeling approach, consideration has been given to existing and planned efforts by other organizations in order to gain mutual benefits where possible. As part of our model selection effort the USACE, Jacksonville District, has worked closely with the SJRWMD who originally developed the Lower St. Johns River hydrodynamic and water quality models for their WSIS and Total Maximum Daily Loads (TMDLs) (Sucsy and Morris, 2002). The USACE has made improvements to the EFDC model grids through the refinement of horizontal grid cells in the Federal Channel to improve representation of project channel alternatives. Adopting the SJRWMD WSIS models provides the opportunity to efficiently evaluate cumulative environmental impacts of the project, including USACE historic sea level rise (0.39 ft) and the SJRWMD WSIS future projection of 155 MGD upstream river water withdrawal, due to changes in salinity, water age, and water quality.

The numerical models selected, to meet the objectives of the study are shown in Table 2.

Table 2. Model Selection and primary tasks.

Model	**Boundary Conditions**	**Ship Sim Currents**	**Riverine Shoaling**	**Coastal Shoaling**	**Storm Surge**	**Salinity**	**Water Age**	**DO/ Chl-a**
ADCIRC	X				X			
ADH		X	X					
CMS				X				
EFDC						X	X	
CE-QUAL-ICM								X

Observed Data –Describing Physical Characteristics – Informing Modeling and Analysis

The modeling described in the previous sections is of limited value without adequate observed data to provide a better understanding of the processes and their interactions that govern the characteristics of the St Johns River Estuary and to serve as model input and as a basis for comparisons for calibration and validation of each model. The types of observed data that are required for the modeling described in the previous sections include bathymetry (Table 3), waterlevels (Figure 2), currents (Table 4), waves (Tables 5 and 6), wind, stream flow, rainfall, evaporation, salinity (Table 7), sediment characteristics, dissolved oxygen (DO) (Table 7), and chlloraphly-a (Chl-a). After identifying the types of observed data required, the next step is to gather data previously collected. Existing data were gathered from sources such as the SJRWMD, USGS, NOAA, and NOS. Once the existing data had been inventoried, any gaps in coverage were identified. Since the existing data has several sources and purposes no recent data including the basic physical parameters (concurrent currents, waterlevels, salinity, and waves) in the vicinity of navigation channel project was found. In order to fill this gap, the USACE conducted a synoptic field measurement study for this project from May through July, 2009.

Bathymetry

Bathymetry data is required to define the model domain and is the parameter that represents the channel alternatives that we are investigating. The primary source of bathymetry data for much of the areas outside navigation channels is the National Ocean Service (NOS). For navigation channels, the primary source of bathymetry data is the USACE channel surveys that are conducted for various purposes on at least an annual basis.

As part of the Jacksonville Harbor GRR-2 Deepening project, USACE-SAJ developed bathymetry dataset compilations based on USACE surveys for all the hydrodynamic models (ADCIRC, ADH, CMS, EFDC) which include the St Johns River, the Federal Channel, the AIWW, tidal creeks, and salt marshes north and south of the river. These models require accurate representation of the Federal Channel, tidal creeks and salt marshes which is critical to accurately simulating the hydrodynamics in the St Johns River. All bathymetry used in these models are referenced to NAVD88.

Project evaluation requires bathymetry representing the existing condition of the Federal Channel and the St. Johns River and vicinity using the best available bathymetric surveys, from 2009 and earlier, of the St Johns River and vicinity, including the Federal Channel, AIWW, and Tributaries. Table 3. shows the USACE surveys that were used for the existing condition bathymetry dataset.

Table 3. Jacksonville Harbor – St Johns River 2009/2010 Existing Condition Surveys

Survey	Description
St Johns River- Jacksonville Harbor Federal Channel	
09-047 PCS * (NAVD88)	St johns River Bar Cut 3 to Hart Br
09-028 (BB)	SJR Bar Cut 3 to Terminal Chan Bank to Bank
09-028 PCS 28 ft Proj	Hart Br (Buoy 80) to Main St Br
09-031nfp_LL_unsorted	StJohnsRiv @Trout River
St Johns River Vicinity	
09-028	SJR Tributaries
09-097	Mill Cove
09-098 PCS	AIWW Fernandina to Nassau Snd
09-027 * (NAVD88)	SJR_ entrance to Mayport
09-025NAVD88	Mayport
08-127NAVD88	x AIWW Sisters Crk Nassau Snd to near StJohnsRiver (Cut 7 to 27c)
08-092NAVD88	Marine Terminal BLountIS
06-154NAVD88	Mill Cove Channel
04-054NAVD88	x AIWW Sisters Crk Northend
02-178NAVD88	x AIWW Beach Blvd
01-089NAVD88	x Mathews Brdge to dwntwn 1 track

Waterlevel

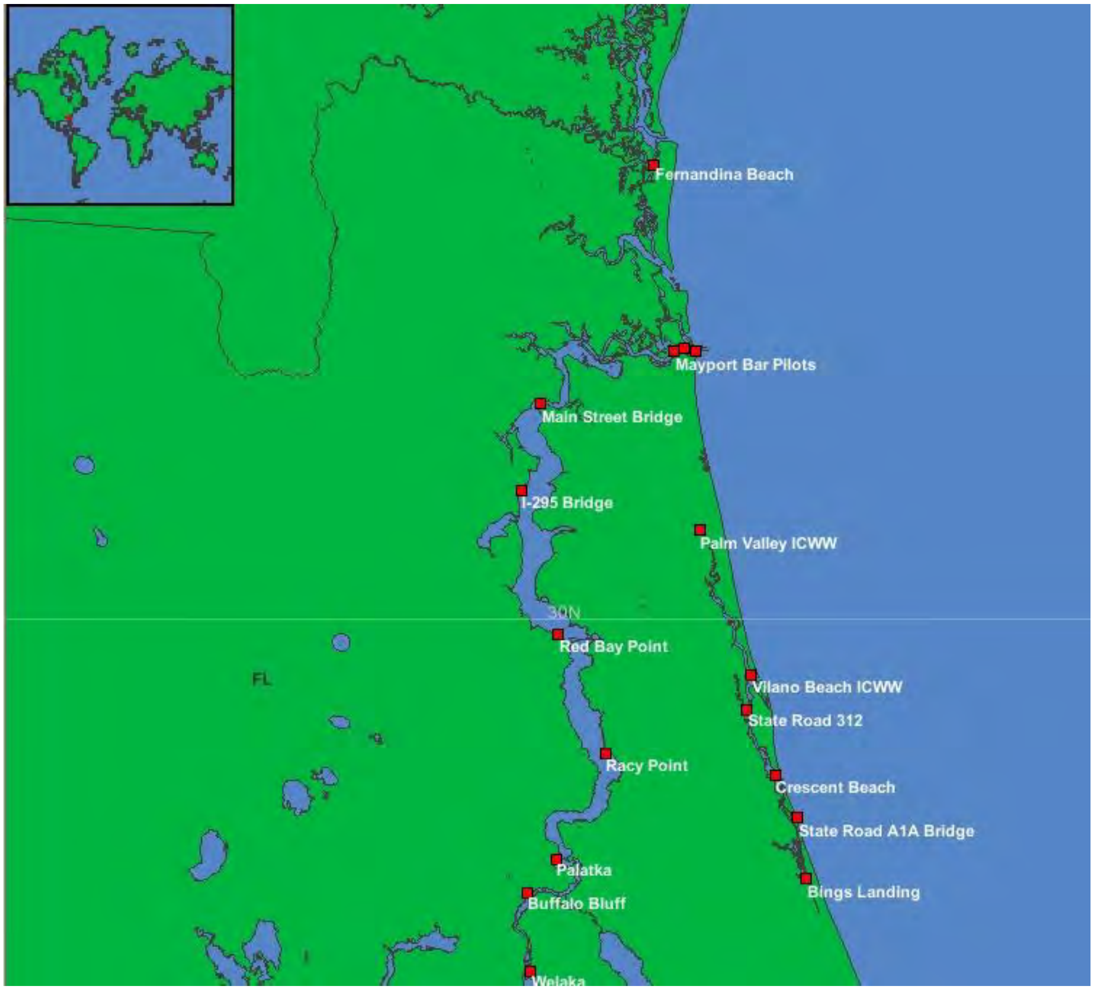

Figure 2. Active NOS Waterlevel gages

Currents

NOS ADCP Currents – Data Inventory

Table 4. NOS ADCP Current Data Inventory

Station ID	Station Name	LAT	LONG	Dates
SJR0301	Dames Point	30.3865	-81.55383	May-Jul 2003
SJR0302	Trout River	30.37833	-81.62833	May-Jul 2003
SJR0303	**Buoy #5**	**30.39667**	**-81.375**	**Jul-Oct 2003**
SJR0304	**Buoy #6**	**30.398**	**-81.3972**	**Jul-Sep 2003**
SJR9801	**StJohns River Ent**	**30.40067**	**-81.386**	**Apr-Jul 1998**
SJR9805	Dames Pt Br	30.3846	-81.55492	Jul-Aug 1998
SJR9806	Trout River	30.38358	-81.62785	Jul-Sep 1998
SJR9807	Blount Is East	30.39228	-81.50872	Jul-Sep 1998

Figure 3. St Johns River Entrance NOS ADCP Locations.

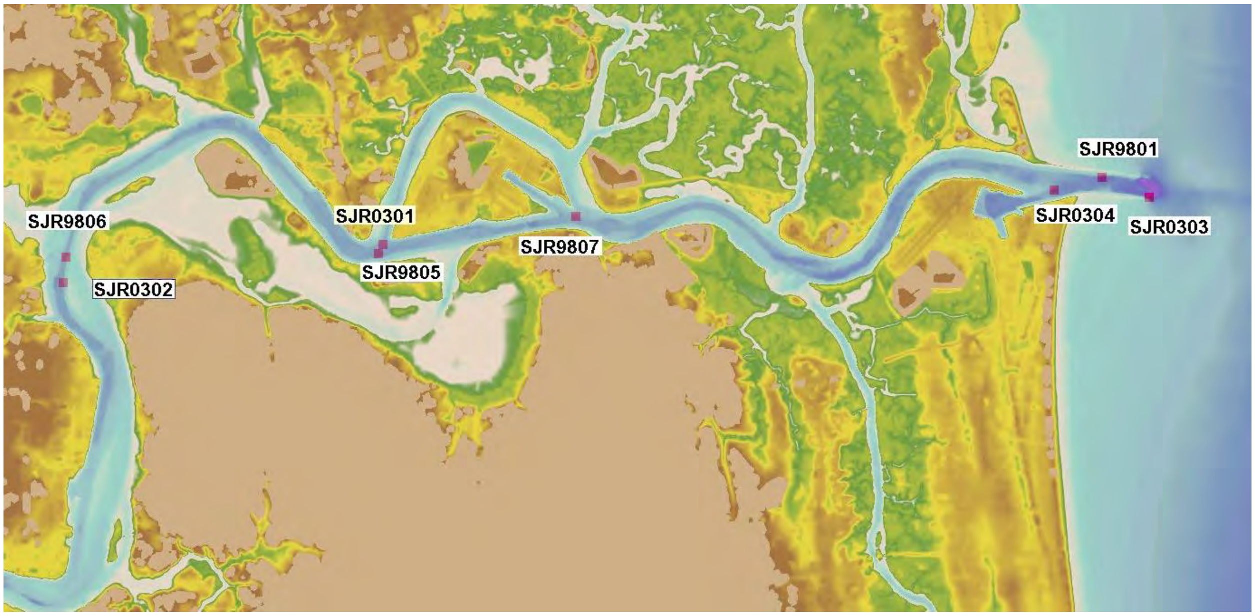

Figure 4. St Johns River NOS ADCP Locations.

Waves

Table 5. 41012 - St. Augustine, FL 40NM ENE of St Augustine, FL

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002						Wv	Wv	Wv	Wv	Wv	Wv	Wv
2003	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2004			Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2005	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2006	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2007	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2008	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2009	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
2010	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv
Wv – Wave Height, Period, Direction												

Table 6. Jacksonville and Fernandina ODMDS ADCP Wave, Waterlevel, and Currents

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006								Wv	Wv	Wv	Wv	Wv
2007	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv	Wv			
Wv – Wave Height, period, Direction												

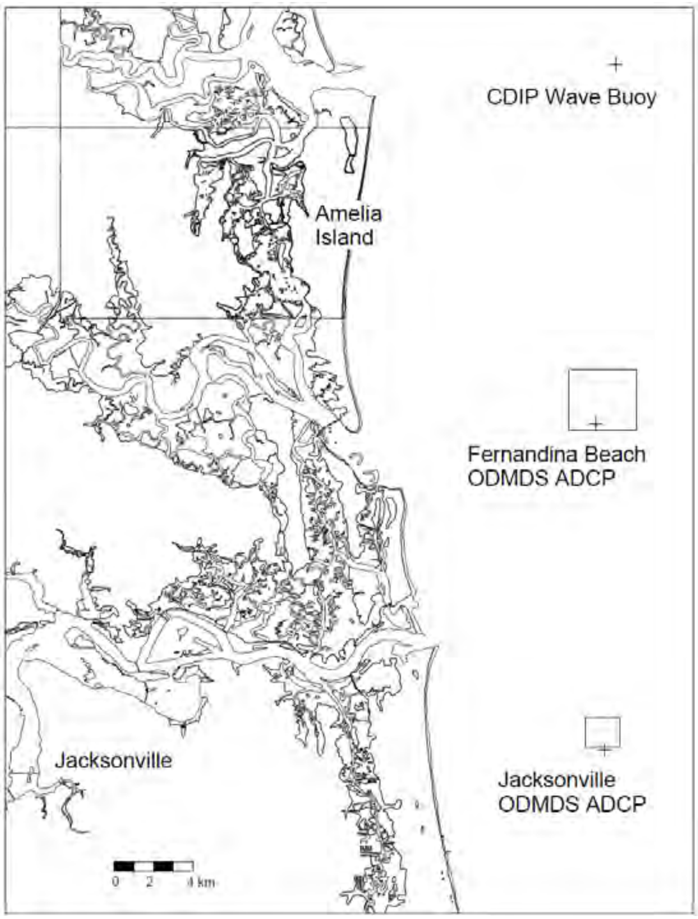

Figure 5. Jacksonville and Fernandina ODMDS ADCPs and CDIP Wave Buoy Locations.

Salinity, Temperature and Dissolved Oxygen

Table 7. USGS Water Quality Stations

Station Name	Station No.	Begin/End Dates	Salinity	Temp	DO
Dames Point Bridge	302309081333001	2007-10-11 to2012-10-28	T,B	T,B	T,B
Acosta Bridge	02246500	1995-05-24 to 2003-09-29	T,M,B	T,M,B	
Buckman Bridge	301124081395901	1995-06-09 to 2012-08-14	T,B	T,B	T,B
Shands Bridge	295856081372301	1995-04-29 to 2001-09-14	T,B	T,B	
		1995-04-29 to 2001-09-14	M	M	M

T= Top of water column, M= Middle of water column, B= Bottom of water column

USACE 2009 Fieldwork / Data Collection

The project requires the collection of synoptic measurements of ocean and river currents, incident waves, water surface elevations, salinity, and sediment concentrations in the vicinity of the lower St Johns River in Duval County, Florida (Figure. 6). A description of this data collection effort is in Appendix A.

This effort involved the collection of hydrodynamic and suspended sediment data in the LSJR and Federal Channels. The fieldwork consisted of a combination of five fixed mooring stations and 20 shipboard measurement stations (fig. 3). Measurements included (1) current profiles using a towed Acoustic Doppler Current Profiler; (2) current measurements using a Side-Looking SonTek Acoustic Doppler Profiler; (3) conductivitity-tempearature-depth measurements using an Applied Microsystems CTD system; (4) measurements of suspended sediment concentration and particle size spectrum using a Sequoia LISST (laser-based scatterometer) and (5) water level measurements via pressure transducer.

All mounted/fixed instrumentation were in place before the commencement of mobile data collection. Mobile transects took place over a six-day window between which included peak flood and ebb tidal currents during a ‘near-spring’ tide cycle.

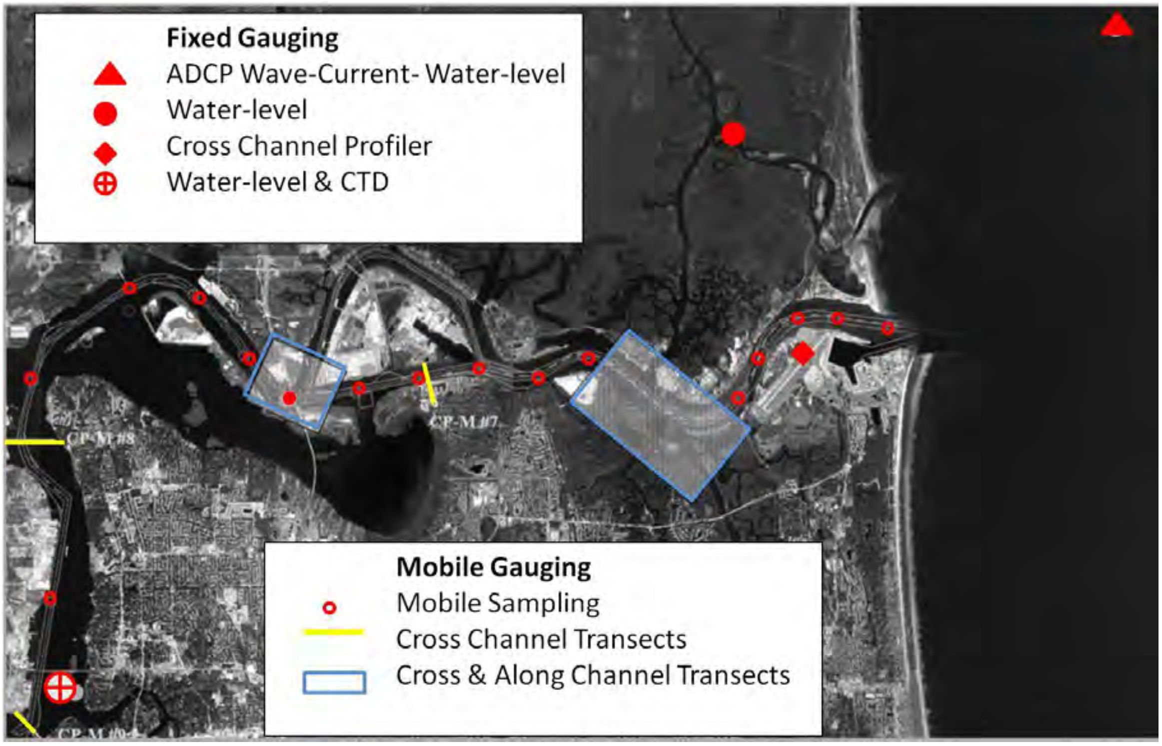

Figure 6. Site Locations for in-situ and mobile instrumentation for Jacksonville Harbor Deepening Project.

Currents

A side-looking current profiler (CP-SL) was used to measure currents at a single downstream location looking across the navigation channel near the Mayport Bar Pilots Dock from 16 June to 29 July 2009. These current data were gathered continuously for 40 days that spanned the spring tidal cycle over which mobile transects were made. Current profiles along 20-miles of the Federal Channel were obtained from 16-21 June 2009 using a downward-looking boat-mounted mobile current profiler (CP-M). at one-mile from the river mouth at the Atlantic Ocean, upstream to the Mathews Bridge. Sampling was centered at peak flood or ebb tide. Across-channel mobile transects were taken at the confluence of other major tributaries, the Intracoastal Waterway (IWW) and the St Johns River.

Salinity and Suspended Sediment Concentration

Salinity and Sediment Concentration data were collected from 16 – 21 June 2009 by casting the CTD and LISST over the side of the research vessel during mobile transecting events. At onemile intervals, measurements of Salinity were made at 0.5m increments through the water column and a measurement of Suspended Sediment Concentration was made approximately 0.5m from the bed.

Waterlevel

Water level (WL) data were gathered at WL #1 and WL #2 sites for a 40-day period (16 June – 29 July 2009) and for a 90-day period (18 April – 29 July 2009) at WL #3 and WL #4. Northing, Easting (NAD 83) and Elevation (NAVD 88) for all gauges were be reported. A single CTD will be installed on the water level mount for the most up-estuary water level gauge (WL#1).

Waves

The incident wave field was measured at *N 30 27.028'; W 81 23.895'* approximately three miles north of the St Johns River Entrance at an approximate depth of 20 ft. The directional wave gage (DW) was deployed for 90-day period between 16 June and 29 July 2009 to measure water levels and directional wave information.

Hydrodynamic and Transport Modeling

System Wide Hydrodynamic Boundary Conditions (ADCIRC)

The purpose of this ADCIRC modeling effort is to provide improved hydrodynamic offshore, riverine, and Atlantic Intracoastal Waterway boundary conditions for the navigation channel design and riverine sediment transport modeling (AdH), the environmental impacts modeling (EFDC) and the coupled coastal hydrodynamic, wave, and sediment transport model (CMS).

ADCIRC simulates a wide range of scales in one model setup to efficiently represent large domains and high resolution in selected areas. The flexible mesh cell size represents small-scale bathymetric/topographic features with high resolution mesh cells in areas such as the St Johns River and tributaries in the vicinity of the federal channel, the marsh areas, and the AIWW (Figure 7.). The ADCIRC model includes improvements in the volume/flow exchange between the marsh areas and the St Johns River and represents the marsh areas to the north and south of the St Johns River. The mesh includes the adjacent inlets, St. Marys, Nassau Sound, Ft George, St Augustine, and the AIWW, which ensures that subtidal responses of adjacent estuaries are included in the task specific models. The ADCIRC hydrodynamic model is used to generate boundary conditions in the form of 1) tidal elevations, 2) depth-integrated velocities, and 3) velocity residuals. Three sub-domains within the computational mesh correspond to the AdH (ADaptive Hydrology/Hydraulics), CMS (Coastal Modeling System), and EFDC (Environmental Fluid Dynamics Code) model domains (Figure 8). A detailed description of the ADCIRC hydrodynamic waterlevel and current boundary modeling is located in Attachment F. ADCIRC Boundary Conditions for Project Design and Impact Analysis.

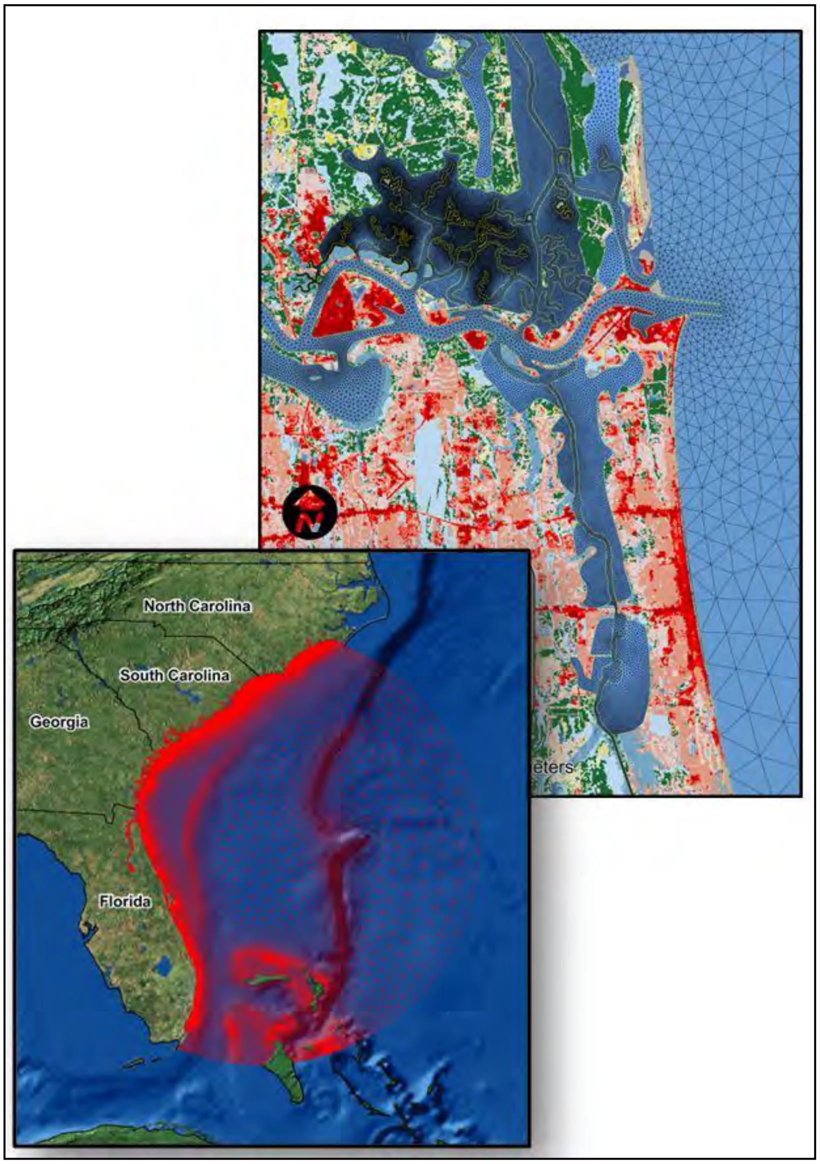

Figure 7. ADCIRC Computational mesh for the South Atlantic Bight and St Johns River (inset).

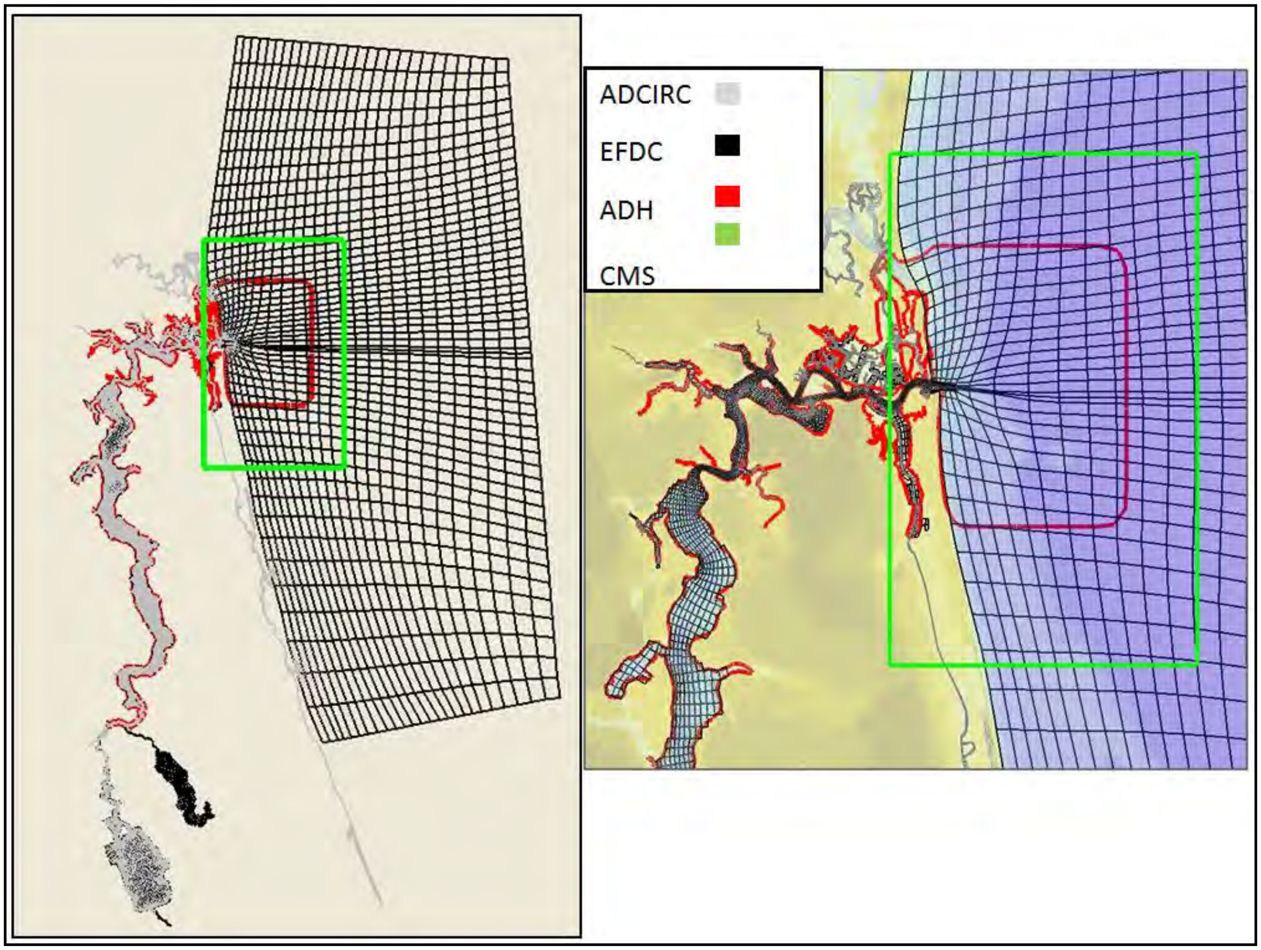

Figure 8. Task specific model boundaries where ADCIRC provides boundary conditions.

Engineering Design Modeling and Analysis

<u>Hydrodynamic Modeling for Ship Simulation (AdH)</u>

A high-resolution hydrodynamic model was developed to simulate the tidal cycle in the domain under Jacksonville Harbor. Figure 9 shows the triangular mesh that is used in the federal channel and in the areas depicting different limits of widening. It was observed that the model performed reasonably well in simulating the temporally and spatially varying tidal fluctuations and currents from the Atlantic Ocean to the St. Johns River.

The success of the model can be traced to its ability to represent spatially varying characteristics (roughness coefficient and eddy viscosity), time-varying boundary conditions, and wetting-drying processes in an irregular network of finite elements. Because of the tidal hydrodynamics, the water levels and the currents change in the channel. The driving forces including inflow and tidal fluctuations at the boundaries helped generate the results by the model for pre- and post-dredging conditions.

A reasonably good calibration of the AdH model for Jacksonville Harbor was performed by comparing with the observed data from June 16, 2009 at 3:00 pm to June 19, 2009 at 3:00 pm. The calibrated model was validated successfully using the tidal boundary condition data from June 26, 2009 at 12:00 am to June 29, 2009 at 12:00 am. The simulated results for both water levels and currents were agreeable compared to the observed data. It is observed that the simulated current speeds are strong in the entrance channel near the shore line. After the successful calibration and validation, the AdH model for Jacksonville Harbor was used to simulate the alternatives for ship simulations. Further details of this analysis are available in Attachment G. AdH Hydrodynamic Modeling for Ship Simulation, Riverine Channel Shoaling and Bank Impacts. The simulated and depth-averaged current velocities for the existing condition and for the seven alternatives were later used for ship simulation.

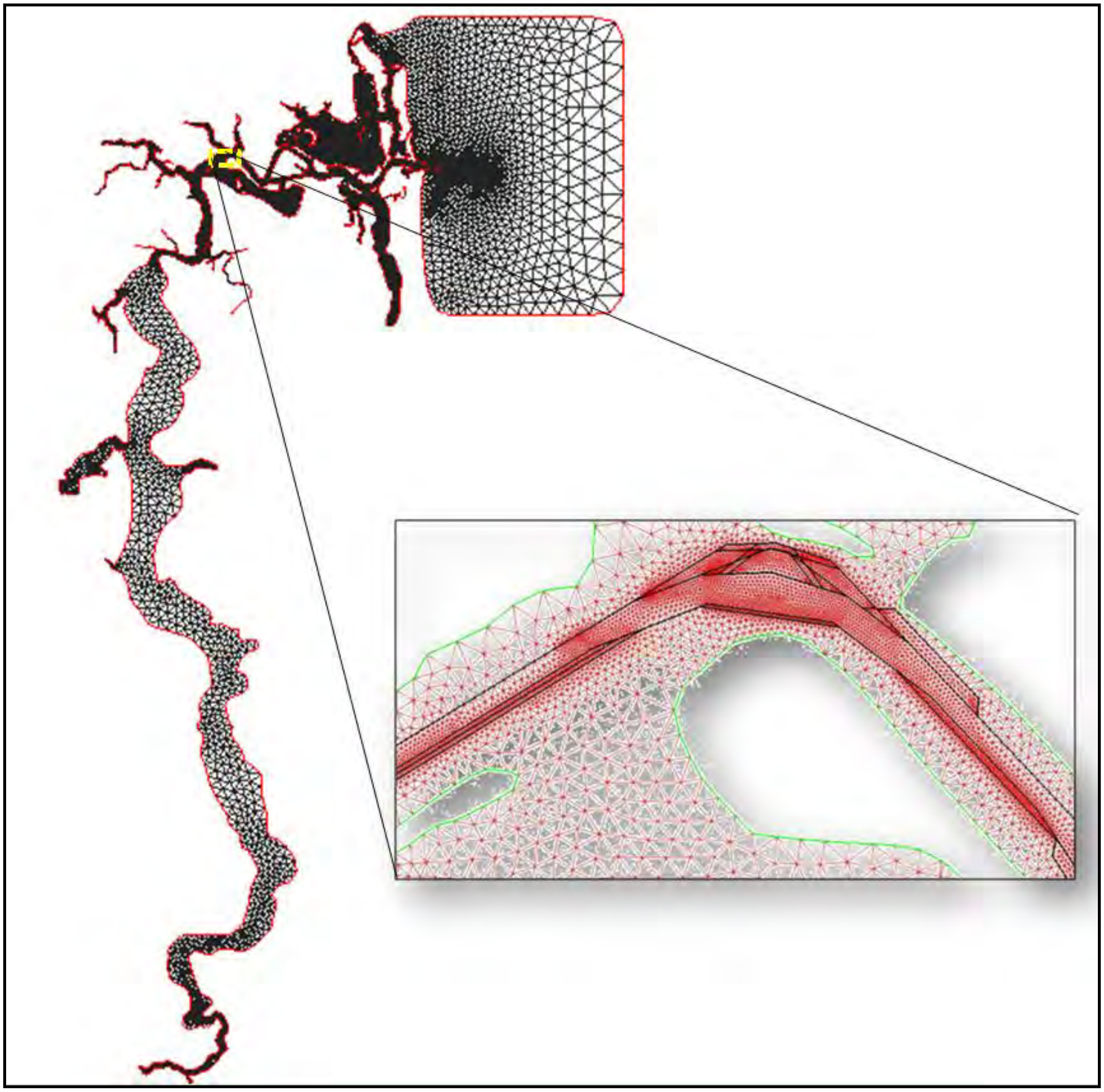

Figure 9. Discretized ADH Jacksonville Harbor - St Johns River model domain based on finite elements.

Ship Simulation and Channel Design

Development of deep-draft navigation projects affected by tides, river currents, and wave motion requires the use of models and ship simulator studies. The dynamic environment embracing deep-draft navigation project sites can never be fully understood applying only the static tools of observation and measurement that engineering commonly uses. Designers and planners can discover and dissect the most efficient navigation system layout, with each of its component's individual geometry, by studying the performance of design vessel ship models, transiting project domain limits, depicted as proposed channel and turning basin system alternatives, on the ship simulator. Navigation model studies are used to determine the adequacy of a proposed project improvement plan and to develop possible design modifications to ensure project safety, efficiency, and minimum adverse impact to the environment. Because of the complexity of tidal and river currents and effects of wind, waves, and sediment movement on ship navigation, combined analysis of physical scale models, numerical models, and computer based ship simulation models is often necessary to resolve proposed project issues (EM 1110-2-1613, Hydraulic Design of Deep-Draft Navigation Projects, 31 Aug 2002, Chapter 13, Navigation Model Studies). The general guidance presented in this manual is based on average navigation conditions and situations. The design engineer will adapt these guidelines to the local, site-specific conditions of the project. And, unless special circumstances exist whereby a deviation is approved by Headquarters, U.S. Army Corps of Engineers, the final project design will be developed by application of a ship navigation study, incorporating real-time ship simulation tests with local professional pilots (EM 1110-2-1613, 31 Aug 2002, 1. Purpose, as stated in the cover letter signed by Joseph Schroedel, Colonel, Corps of Engineers Chief of Staff).

A deep-draft navigation study begins with meetings and discussions focused on navigation system improvements that are believed to be necessary for continued safe operation, by the professional harbor pilots who command vessels that use the channels and basins included in the system layout. Generally, the pilots suggest channel straight section and turn wideners that enhance vessel transit efficiency and safety. They may suggest new turning basin components, or construction that increases the diameter of existing turning facilities. As the vessel fleet increases its operating draft, the pilots advocate for increased channel depth. In special situations where a restriction to operations exists based on water currents, the pilots contribute time and efforts toward engineering investigations focused on removal of the restriction through the development of structural components that moderate water current force, and ease the flow of water through the system. These early discussions are conducted with engineers and planning specialists in attendance. The engineering team begins early to encourage movement of the study to the simulator environment, for efficient iterative development of the best alternative that will define project physical limits, and test a proposed design.

The engineering simulator design team observed vessel transits from the bridge of an inbound and outbound container vessel, as the harbor pilot guided these transits to and from the vessel's berth at Blount Island. It is common practice to board a vessel during operation, under supervision of the harbor pilot, to observe vessel movement through the system, and witness operation within the constraints of the existing system layout. These transits clarify operation inefficiencies, and sharpen their focus for accurate presentation on the simulator. The simulator design team can do their best work at problem solution when the problem is fully understood and accurately duplicated for investigation in the simulated environment. This important component of simulator preparation occurred on February 24 and 25, 2009. During these transits, the simulator design team collected digital photographic images of the navigation channel and adjacent shoreline features. These images become the visual scene component of the simulator presentation that represents the channels, basins, and shoreline, with adjacent and nearby background areas. During navigation, in addition to channel limit markers and course range delimiters, the harbor pilot references shoreline features that he associates with acceptable progress along an intended sailing course. These visual cues are coincidentally noticed, habitually learned, and eventually relied upon, as the pilot gains experience in a particular harbor channel network. In addition to the visual component of the simulator experience, the geometry of the channel layout with adjacent shoreline and berthing areas is entered into the simulator computer data base. The geometry of the existing condition at the facility, in addition to the geometry of alternative channel layout configurations that include pilot suggested improvements, are entered into the computer data base for testing. The dynamic features of the simulator are entered as water currents, wind, and hydrodynamic ship forces. Bridge command forces in the form of engine throttle setting and steering rudder position complete the dynamic input to the model. During simulator testing, a professional harbor pilot navigates a hydrodynamic model of the project design vessel through the simulator domain of the proposed project alternatives, to select and test the best configuration that satisfies intended project purpose feasibly, with full accommodation for navigation safety and environmental preservation.

Model development for the GRR-2 and testing of alternatives were completed during the period January to December 2010. This work included two testing sessions attended by the St. Johns Bar Pilots, and a testing session focused on turning basin placement and dimensioning, attended by the professional Docking Masters. A detailed report of this work is included in Attachment I. Ship Simulation - Navigation Study for St. Johns River GRR-2 Improvement Project Data Report (March 2012). The report discusses each component of simulator development and utilization for selection and testing of the GRR-2 recommended Alternative. In addition to the above, the report includes testing track plots and pilot evaluations of each simulated run conducted. The track plots and the evaluations are considered intellectual property of the pilots and may be viewed at the USACE District Office in Jacksonville .

Project impacts

<u>Modeling and Analysis for Project Channel Shoaling Rate & Volume Estimates</u>

Riverine Channel Shoaling Rate & Volume Estimates (AdH)

In order to evaluate riverine channel shoaling rates and estimate future maintenance volumes due to the project, the AdH sediment transport processes was included in the model. The AdH sediment transport model for Jacksonville Harbor was later run for three months from May 1 through July 31, 2009 for both existing condition and for the preliminary alternative with-project condition depth of 46-ft MLLW. The observed bed levels were compared with the model results. A reasonable agreement was obtained between the observed data and the model results. Additional AdH modeling has begun for the Locally Preferred Plan, which is the Tentatively Selected Plan, with an inner channel project depth of 47 ft MLLW and a length which extends from Mile 0 to Mile 13.1. This work will be completed prior to and included in the final draft of this GRR.

The AdH sediment transport model simulated the bed level changes for both existing and with-project (46-ft depth) conditions. Based on the simulations, the shoaling rates and volumes were computed that would result in deepening and widening of the channel. The with-project condition results in an overall increase in shoaling volume by approximately fifteen percent. Model results for a subset of Section 1, from Cut 5 through Mile Point Cut-13, indicate no significant increase in shoaling volume rates due to the project alternative. Model results for Section 2, from Milepoint Cut-14/15 to Cut-42, indicate an increase by a factor of 5 in shoaling volume rates due primarily to the Blount Island Turning Basin project alternative feature in this Channel Section. Model results for Section 3A, from Mill Cove Cut-43 to Cut-45, indicate an increase in shoaling volume due primarily to the Brills Cut Turning Basin project alternative feature in this Channel Section. Of the estimate total 3-month shoaling volume of 5,769 yd^3 for Section 3A, the Mill Cover turning basin for with-project condition contributes 4,672 yd^3 . A total of 81 percent of the shoaling occurs within the turning basin area.

The average shoaling rates (based on the rates of bed displacement) are computed at the turning basin in the Mill Cove and Bartram Island area. Based on the average modeled shoaling rate of 0.0034 ft/day, an annual increase of 1.25 ft is predicted fro the the turning basin at the Mill Cove area. Similarly, based on an average modeled shoaling rate of 0.0044 ft/day an annual increase of 1.6 ft in the bed is predicted for the turning basin near Bartram Island.

The AdH hydrodynamic model for Jacksonville Harbor was used to investigate the effects of creating islands as a beneficial use of dredged material in Mill Cove. No significant effect on water levels and volumes of water flowing into and out of Mill Cove was observed by examining the model results. Slight reductions in water velocities can be expected to occur in the immediate vicinity of the islands. In addition, changes in sedimentation rates and patterns could occur in locations near the islands.

Coastal Channel Shoaling Rate & Volume Estimates (CMS)

In order to evaluate coastal processes and channel shoaling rates at the entrance to the St Johns River and estimate future maintenance volumes due to the project, the Coastal Modeling System (CMS-FLOW) was used. Attachment H. CMS Hydrodynamic Modeling for Coastal Processes and Channel Shoaling, documents the investigation of the coastal processes in the vicinity of the St Johns River entrance which provides a basis for evaluating the mechanisms which contribute to the coarse grained shoals frequently found in the Federal navigation channel between the jetties and for evaluating the impacts of channel deepening to the adjacent beaches due to changes in transport pathways at the entrance. A coastal process analysis of the St Johns River entrance was conducted including a historical shoaling estimate based on historical bathymetry surveys of the channel and adjacent areas and the coupled hydrodynamic wave and sediment transport model, CMS-FLOW.

Currents, waves, sediment transport, and morphology at the St Johns River Entrance form a coupled dynamic system. This complex system dictates the transport of littoral sediment into and out of the navigation channel and to or from adjacent beaches. In order to determine the pathways and transport rates in this inlet system a coastal inlet processes model was used to simulate historical morphologic changes. Attachment H. CMS Hydrodynamic Modeling for Coastal Processes & Channel Shoaling, presents the modeling results of recent changes to the inlet system-the entrance channel was deepened to a 50 ft MLLW project depth in 2012 by the Navy. The CMS model domain and the Mayport deepening project with the bathymetry modified to represent the 50 ft MLLW (15.2 m) project depth as well as depths for advance maintenance, which resulted in depths of 54 ft MLLW (16.5 m) in some areas are shown in Figure 10. Additional analyses are planned for the Jacksonville Harbor GRR2 modifications to the inlet system.

The existing authorized civil works entrance channel is 800 ft wide and 42 ft MLLW (12.8m) deep (see Plates 2 through 4, Appendix A). The project alternatives under consideration include: widening the channel varying amounts (up to 300 ft) starting about 1.0 mi east of the Atlantic Intracoastal Waterway (AIWW) and extending about 4.8 mi up river; deepening the inner channel to 47 ft MLLW (LPP plan) for the majority of the project; deepening the entrance channel to 49 ft MLLW (LPP plan); providing advanced maintenance areas equal to 2 ft for existing shoaling areas or anticipated shoal areas; and providing turning basins adjacent to Blount Island and Brills Cut (Plates 2 through 4, Appendix A). The US Navy (USN) has deepened the entrance channel, known as Bar Cut 3, through the inside of the jetties to the Mayport Entrance Channel, to a project depth of 50 ft MLLW.

In order to estimate the annual shoaling rate for the Bar Cut 3 Ebb Shoal section of the channel for the Mayport Deepening, the shoal volume for the simulated storm event No. 2 (Table 2) was weighted proportionally to the significant wave and storm duration for each of the 7 storm events shown in Table 2. These weighted estimates of shoal volume for each event were summed to calculate an estimate of the annual shoaling in the Bar Cut 3 Ebb Shoal section of the channel. The annual shoal volume for the without Mayport condition is 47 KCY and for the with Mayport condition, 105 KCY. This represents an increase in annual shoal volume of 2.2 times. Similar to the volume the bed level change from the simulated storm event No. 2 was weighted proportionally to the significant wave and storm duration for each of the 7 storm events and summed to calculate an estimate of the annual bed level change in the Bar Cut 3 Ebb Shoal section of the channel. The estimated annual bed level change for the Mayport deepening is approximately 2.5 ft. (Table 2).

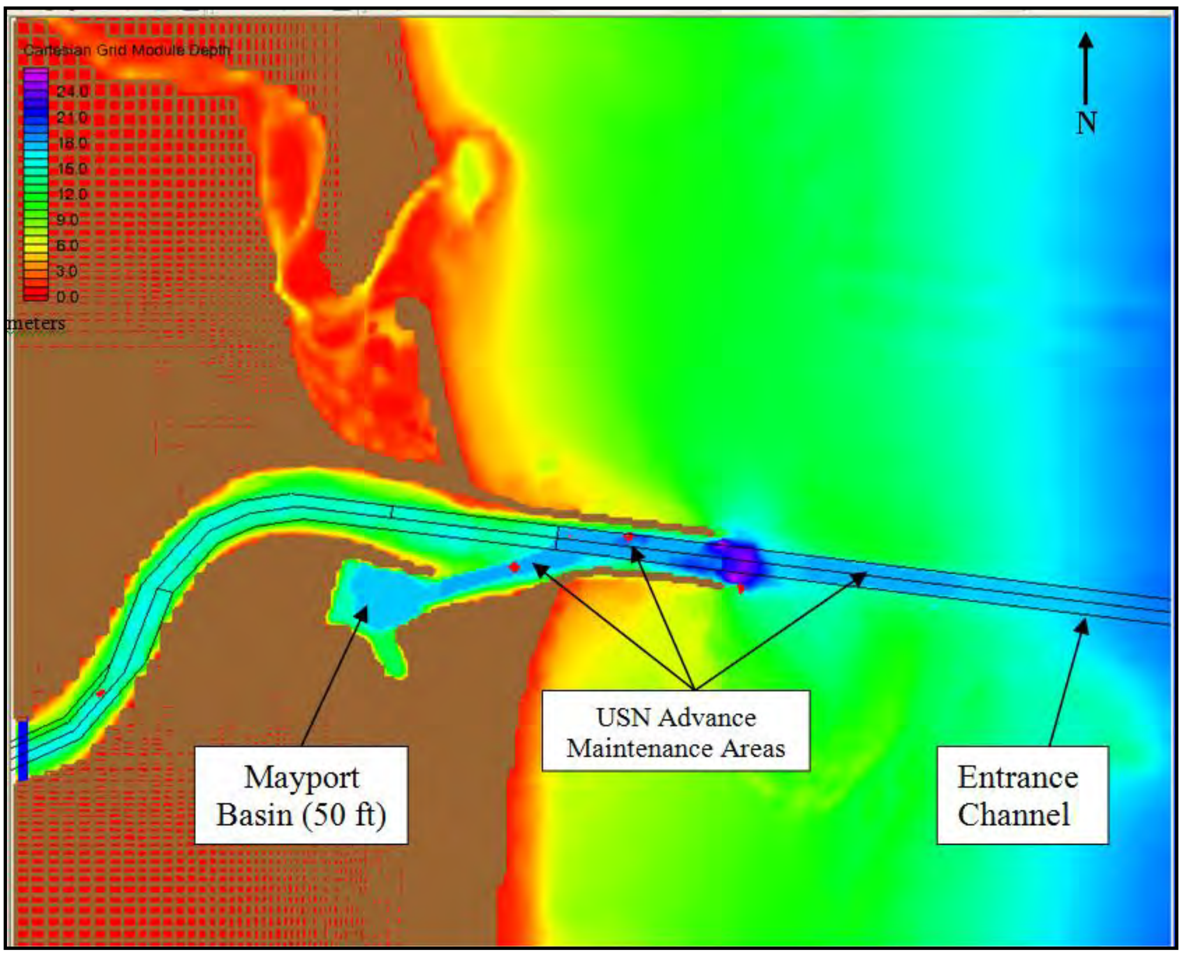

Figure 10. Jacksonville Harbor - Mayport Deepening Bathymetry Scenario.

Bank and Ship Wake Impacts

At Jacksonville, a project purpose is to allow larger vessels with deeper drafts to sail in the deepened channel. Viewed in the context of the Bernoulli principle, the increased immersed vessel cross section as a fraction of the newly deepened channel cross section has a functional relationship with vessel wake generated. More specifically, the percentage of channel cross-section blocked by the submerged vessel is directly proportional to ship wake height. Vessel speed also has this relationship with wake. Although increasing vessel transit speeds is not a project purpose, and speed can be regulated through instruction and enforcement, more needs to be understood regarding the exact nature of the relationship between channel cross section blockage and generated vessel wake characteristics. An understanding of that relationship, and how it applies at Jacksonville, with all other forces considered, is essential for describing vessel wake in the constructed project. Future wake characteristics must be understood to predict shore profile endurance. This insight is especially important in view of the existing situation, whereby identified locations along the river are experiencing bank erosion. The GRR-2 engineering team is developing the process that they will pursue to quantify ship wake characteristics (height and period), in the existing condition. That information will be the basis for an extrapolation of ship wake characteristics in the deepened, constructed project, with the design vessel sailing with an appropriately increased draft. Vessel speed will be held constant in the assumed future condition. Any change in vessel wake characteristics will be included in expected shoreline endurance behavior assessments. Additional analysis focused on channel cross section blockage in the existing condition and in the future condition with proposed project deepening completed, will be conducted to refine our understanding of existing ship wake, and how it may change. This work will be completed over the next several months. A report on this effort will be included in a later version of the Draft report. A full report on this effort will be included in the Final Report for the study.

Projects Impacts to Storm Surge (ADCIRC)

In order to evaluate the potential impacts of the deepening project to storm surge a coupled hydrodynamic and wave modeling system, ADCIRC (hydrodynamic) plus SWAN (wave) has been setup and calibrated for 2 historic storm events. A description of the setup and calibration is located in Attachment J. Hydrodynamic Modeling for Storm Surge and Sea Level Change. This modeling effort is in progress to provide storm event surge assessment including USACE sea level rise rates (EC 1165-2-212) for the proposed project alternative channel deepening.

The ADCIRC+SWAN Storm Event Modeling for Jacksonville Harbor Navigation Channel Design study requires application of water level data from two different storms to calibrate and verify the ADCIRC + SWAN model. Because the study seeks to examine water levels during extreme events, ideal storms to calibrate and verify the model are those that caused the highest observed storm surges in the project area and had accurate measured data at multiple locations along the river.

To select the appropriate storms, this study relies on an ongoing Taylor Engineering / Baker AECOM Georgia and Northeast Florida storm surge study (GANEFLSSS) for the Federal Emergency Management Agency (FEMA).

Calibration and validation of the coupled ADCIRC+SWAN hydrodynamic and wind-wave numerical model for simulation of currents and water levels in Jacksonville Harbor has been completed. Two storm events were used to validate the ADCIRC+SWAN numerical model, Hurricane Dora (1964) and Hurricane Frances by comparing observed time-series water levels at three gages during Dora and fourteen during Frances. Preliminary results indicate the 47 ft project alternative has a minimal affect on the mean low water and mean high water tidal datums and causes no significant increase in peak storm surge elevations.

Modeling and Analysis for Environmental Impacts

Project Impacts to Salinity & Water Age for Ecological Modeling (EFDC)

The USACE-SAJ, as part of its General Re-evaluation Study to improve Jacksonville Harbor (See Figure 11) navigation, is assessing the effects of potential channel modifications on the general circulation, salinity, ecology, and water quality in the St Johns River. The USACE-SAJ chose to use the Environmental Fluid Dynamics Code (EFDC) model to characterize river circulation and salinity for pre- and post-project conditions. The EFDC model was selected based on: 1) it's ability to simulate the hydrodynamic and transport processes required for evaluation of the navigation project impacts, 2) it's extensive use and acceptance by research institutions, government agencies, and consulting organizations (Hamrick, 2011), and 3) because there is an existing EFDC model of the St. Johns River that was developed by SJRWMD for use on their St. Johns River Water Supply Impact Study (WSIS) (SJRWMD, 2011). SJRWMD (2011) presents the completed application of the model to quantify the effects of water withdrawals on hydrodynamics throughout the St. Johns River. The SJRWMD EFDC model simulated a 10 year period, 1996 through 2005, for the St. Johns River WSIS (Sucsy et al.,2010). Using this model application for the Jacksonville Harbor GRR2 deepening study, provides an excellent opportunity to evaluate cumulative impacts of the project deepening, sea level rise, and SJRWMD estimates of future water withdrawal. Attachment K. Hydrodynamic and Salinity Modeling for Ecological Impact Evaluation documents the setup, sensitivity analyses, validation, and preliminary application of the EFDC model to evaluate the direct impacts to salinity and water age of navigation channel modifications.

Figure 11. Jacksonville Harbor extent and GRR2 project Segments.

Figure 12 shows the USACE Jacksonville Harbor GRR2 horizontal model domain which extends from the Atlantic Ocean to just upstream of Lake George. The EFDC hydrodynamic model was calibrated and verified with monitoring data of water level and salinity collected during 1995 to 2005 for three conditions (wet period, dry period, and wind condition). The overall good agreement between simulated and observed water levels and salinity demonstrates the capability of the model to reasonably simulate these processes in the Lower St. Johns River. Based on the calibration and verification results and preliminary model application, the model is suitable for predicting hydrodynamic and salinity changes in the Lower St. Johns River from the potential channel deepening projects.

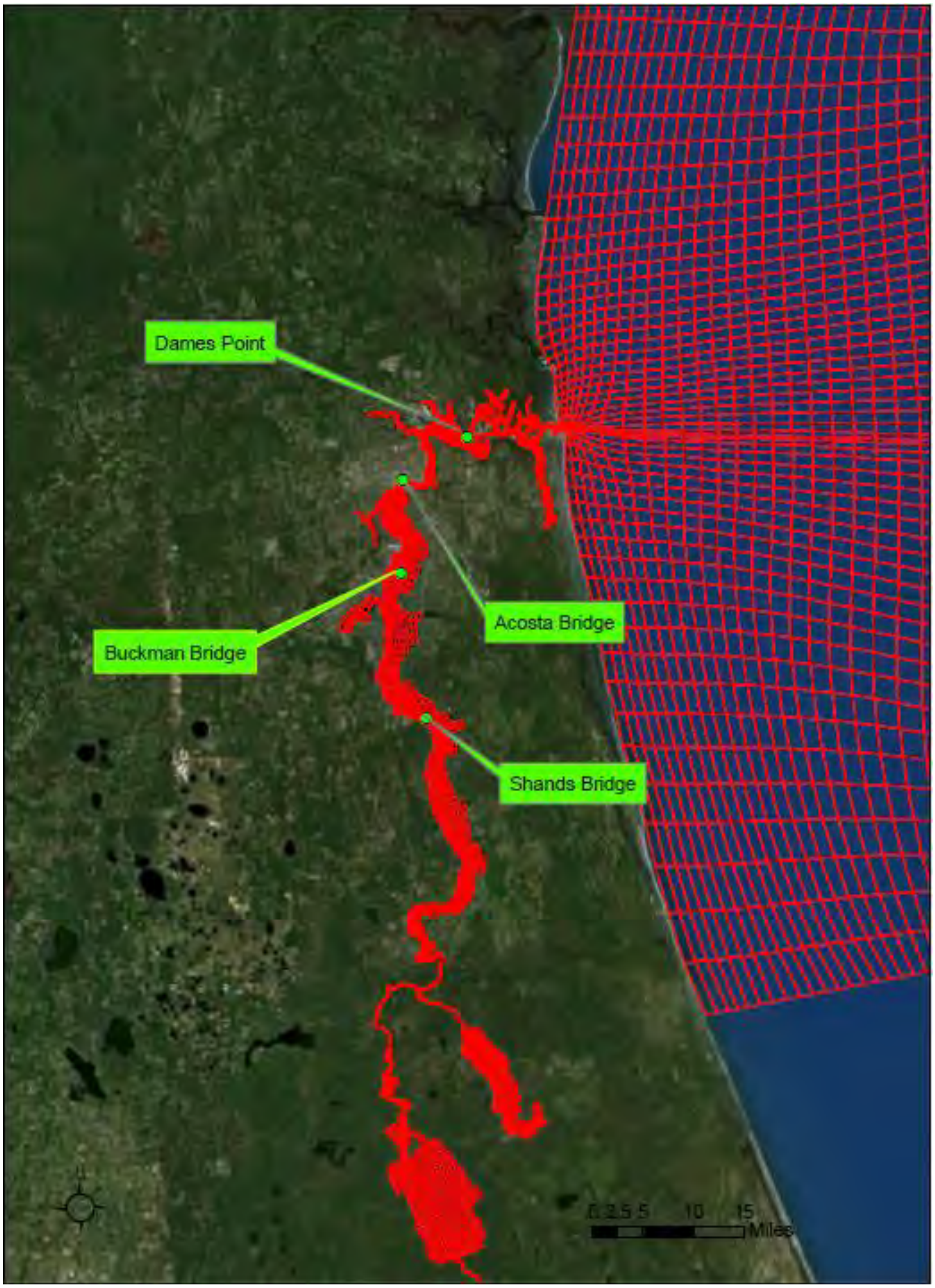

Figure 12. EFDC model domain.

The EFDC hydrodynamic and salinity model, validated for the Jacksonville Harbor Deepening project area, provided the means to assess the direct impacts of channel modifications to salinity and water circulation in the main stem of the Lower St. Johns River. This study applied the model to simulate three preliminary project alternatives (navigation channel dredging to 44 ft, 46 ft, and 50 ft depth below mean lower low water for Segment 1, which is from east of the river mouth at Mile 0 to Mile 13.7) and analyzed the project impact during a six-year evaluation period. The six-year evaluation period includes the lowest river flow during any three-year period in the river's 78-year flow record, as shown in Figure 13, to ensure that assessed project impacts are greater than those during an average year. Therefore, this study's evaluation presents conservative estimates of the impacts of the Jacksonville Harbor Deepening Project. Notably, the evaluations assumed completion of the Mile Point and Mayport deepening projects with the Jacksonville Harbor Deepening. Additional EFDC Salinity modeling has begun for the Locally Preferred Plan, which is the Tentatively Selected Plan, with an inner channel project depth of 47 ft MLLW and a length which extends from Mile 0 to Mile 13.1.

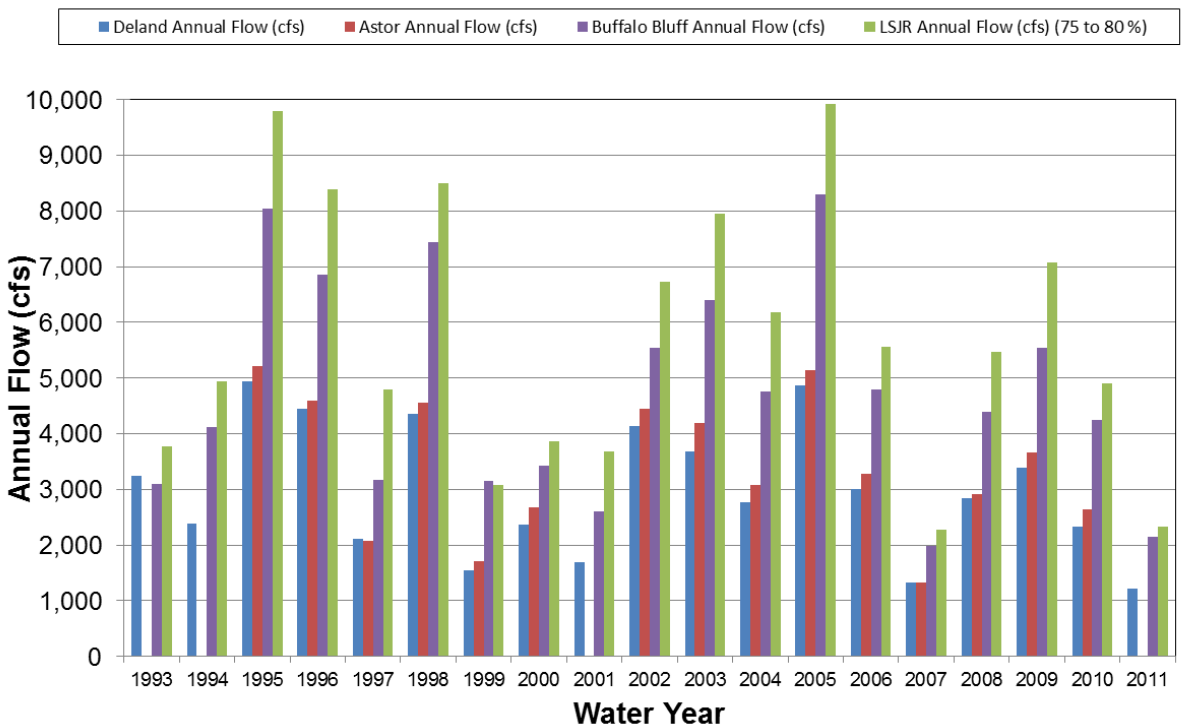

Figure 13. Annual Flows from USGS Stations (1992 – 2011) and the Selected Six-Year Evaluation Period.

The USACE EFDC hydrodynamic, salinity, and water age model results provide input data for five ecological models, namely submerged aquatic vegetation (SAV), wetlands, fish, benthicmacroinvertebrates (BMI), and plankton. These ecological models provide the means to evaluate the potential effect of the Jacksonville Harbor Deepening Project on the ecological system in the Lower St. Johns River. The Ecological Modeling report (EIS?) describes the ecological modeling procedure, ecological modeling results, and impact on ecology of the project. Post-processing of the USACE model salinity and water age results for the 2016 (construction date) and 2068 (50 year project horizon) scenarios provided the ecological model inputs.

Model results associated with conditions immediately after construction (depth only) of the Jacksonville Harbor Deepening Project, summarized below and in Table 8, show that:

1. Project at 44 ft will likely increase tide range by 0.2 ft at Long Branch and Main Street Bridge. The salinity will likely increase by 0.3 – 0.4 ppt from Dames Point to Buckman Bridge and will likely have very small change upstream of Shands Bridge. The project will likely not reduce water circulation in the study area.

2. Project at 46 ft will likely increase tide range by 0.4 ft at Long Branch and Main Street Bridge. The salinity will likely increase by 0.5 – 0.7 ppt from Dames Point to Buckman Bridge and will likely have very small change upstream of Shands Bridge. The project will likely not reduce water circulation in the study area.

3. Project at 50 ft will likely increase tide range by 0.2 ft at Bar Pilot, by 0.4 ft at Long Branch, and by 0.1 ft at Main Street Bridge. The salinity will likely increase by 0.3 – 0.8 ppt from Dames Point to Buckman Bridge and will likely have very small change upstream of Shands Bridge. The project can slightly impede downstream river flow and slightly increase water age as the project allows more ocean water to flow upstream. However, the change in water age is small enough (e.g., water age stays 7 days longer at select water age values per year) that the project will likely not significantly reduce water circulation in the study area.

Cumulative impact model results associated with conditions with 0.39 ft sea level rise and 155 MGD upstream river water withdrawal at 50 years after construction of the Jacksonville Harbor Deepening Project, summarized below and in Table 9, show that:

1. Project at 44 ft will likely increase future tide range by 0.1 ft at Long Branch and Main Street Bridge. Future salinity will likely increase by 0.5 – 0.8 ppt from Dames Point to Buckman Bridge and will likely have very small change upstream of Shands Bridge. The project will likely not reduce future water circulation in the study area.

2. Project at 46 ft will likely increase future tide range by 0.2 ft at Long Branch and Main Street Bridge. Future salinity will likely increase by 0.6 – 1.0 ppt from Dames Point to Buckman Bridge and will likely have very small change upstream of Shands Bridge. The project will likely not reduce future water circulation in the study area.

3. Project at 50 ft will likely increase future tide range by 0.1 ft at Bar Pilot, by 0.2 ft at Long Branch, and by 0.1 ft at Main Street Bridge. The salinity will likely increase by 0.7 – 1.5 ppt from Dames Point to Buckman Bridge and will likely have very small change upstream of Shands Bridge. The project will likely not reduce water circulation in the study area.

In general, the sea level rise and upstream river water withdrawal will likely reduce the above listed project water level impacts by approximately 50%. However, the water age associated with sea level rise and upstream river water withdrawal is about twice more than post-project construction for water ages greater than 150 days. This study applied a set of hydraulic and meteorological conditions that represents dry years to the salinity and circulation modeling, the project impacts presented here are likely greater than the project may cause during an average hydrological and meteorological year.

Table 8. EFDC Salinity Model Results for Depth Only Scenarios

Projects Depths (ft,MLLW)	**Actual Depth (ft,MLLW)**	**Tide Range Change (ft)**			**Salinity Change (ppt)**	
		Mayport	Long Branch	Main St.	Dames to Buckman	Shands
44 [13.7 RM]	47/49	~	0.2	0.2	0.3 – 0.4	~
NED (45) **13.1 RM**	**47/49**					
LPP (47) **13.1 RM**	**49/51**					
46 [13.7 RM]	49/51	~	0.4	0.4	0.5 – 0.7	~
50 [13.7RM]	53/55	0.2	0.4	0.1	0.3 – 0.8	~
RMSE (WL,ft) / (Sal,Top/Bm,ppt)		0.29	0.15	0.14	2.2/3.2 to 0.6/1.5	0.08/0.08

Table 9. Cumulative Impact EFDC Salinity Model Results for Historic Sea Level Rise (SLC1) and Water Withdrawal (155MGD)

Projects Depths (ft,MLLW)	**Actual Depth (ft,MLLW)**	**Tide Range Change (ft)**			**Salinity Change (ppt)**	
		Mayport	Long Branch	Main St.	Dames to Buckman	Shands
44 [13.7 RM]	47/49	~	0.1	0.1	0.5 – 0.8	~
NED (45) **13.1 RM**	**47/49**					
LPP (47) **13.1 RM**	**49/51**					
46 [13.7 RM]	49/51	~	0.2	0.2	0.6 – 1.0	~
50 [13.7RM]	53/55	0.1	0.2	0.1	0.7 – 1.5	~
RMSE (WL,ft) / (Sal,Top/Bm,ppt)		0.29	0.15	0.14	2.2/3.2 to 0.6/1.5	0.08/0.08

The USACE EFDC hydrodynamic and salinity model results provide input data for five ecological models, namely submerged aquatic vegetation (SAV), wetlands, fish, benthicmacroinvertebrates (BMI), and plankton. These ecological models provide the means to evaluate the potential effect of the Jacksonville Harbor Deepening Project on the ecological system in the Lower St. Johns River. Appendix D. Ecological and Water Quality Modeling Reports describes the ecological modeling procedure, ecological modeling results, and impact on ecology of the project. Post-processing of the USACE model salinity and water age results for the 2015 and 2065 scenarios provided the ecological model inputs.

Project Impacts to Water Quality (EFDC/CE-QUAL-ICM)

The Jacksonville Harbor Deepening GRR-2 environmental impact evaluation also included application of the SJRWMD TMDL version of the EFDC hydrodynamic models and the CE-QUAL-ICM water quality model to evaluate the key water quality parameters in the LSJR. Attachment L. Hydrodynamic and Water Quality Modeling for Environmental Impacts documents the setup, sensitivity analyses, calibration and validation, of the USACE TMDL EFDC/ CE-QUAL-ICM model to evaluate the impacts to water quality of navigation channel modifications. The USACE EFDC and CE-QUAL-ICM model domains are shown in Figures 14 and 15. Project impact evaluation is in progress and will be included in the final project report, later in 2013.

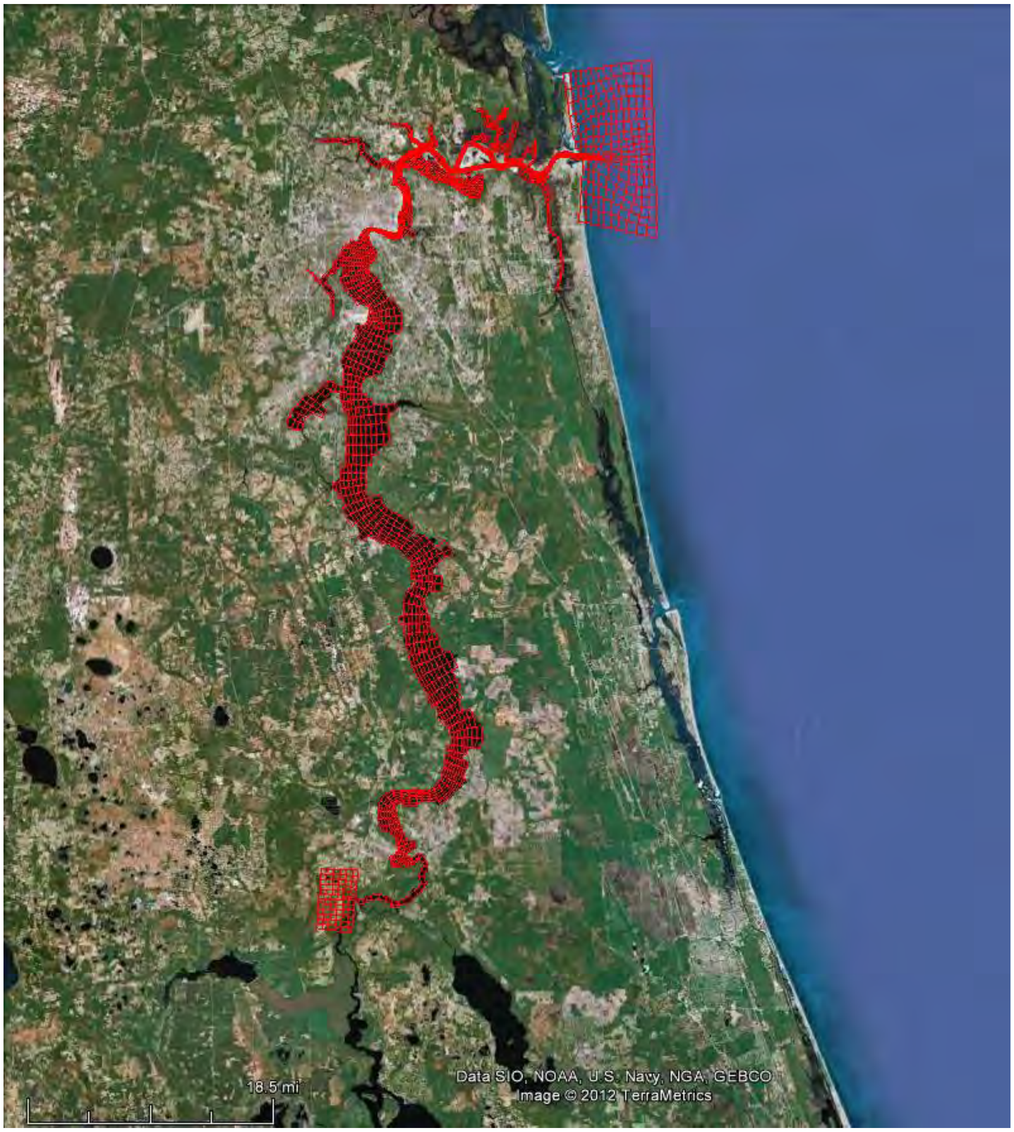

Figure 14. 2001 SJRWMD EFDC Model Mesh on Google Earth Image.

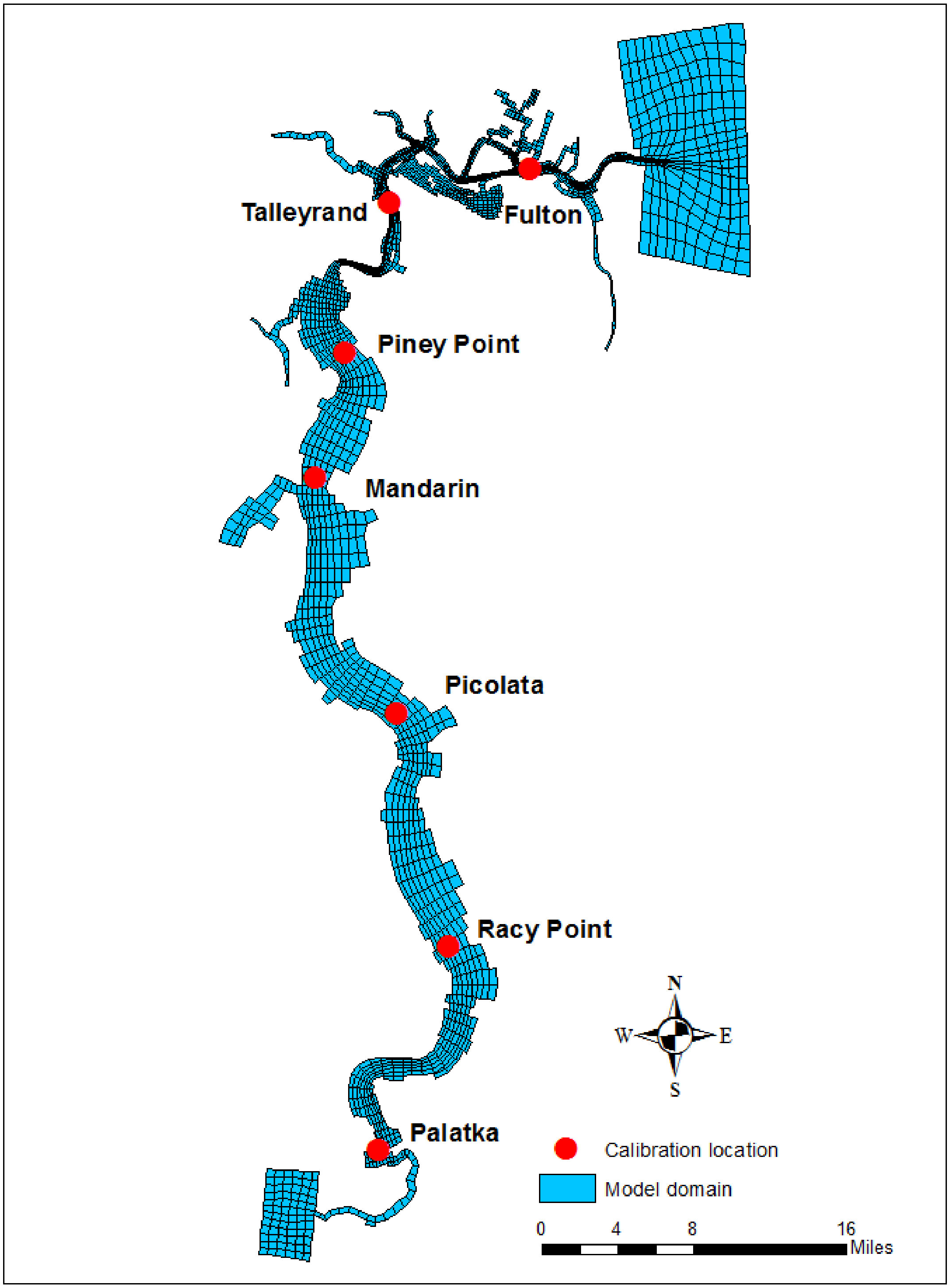

Figure 15. CE-QUAL-ICM model domain and calibration stations.

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ATTACHMENT D

FIELD MEASUREMENT APPENDIX

Field Measurement Project in Support of the USACE's Jacksonville Harbor Navigation Project, Duval County, Florida

Field Measurement Project in Support of the USACE's Jacksonville Harbor Navigation Project, Duval County, Florida

submitted to

Taylor Engineering, Inc.

and

U.S. Army Corps of Engineers, Jacksonville District

Surfbreak Engineering Sciences, Inc.

315 N. Lakemont Ave., Suite A

Winter Park, Florida 32792

Conducted under:

Contract W912EP-06-D-0012 'A-E Services for Water Resources Engineering for Civil Works Projects Mainly within the Jacksonville District'

Subcontract Agreement C2009-030 'Jacksonville Harbor Navigation Project, Field Data Collection'

Draft: September, 2009

1. Background and Overview

The U.S. Army Corps of Engineers (USACE) Jacksonville District (SAJ) is conducting a feasibility study of modifications of Jacksonville Harbor, with the goal of improving ship navigation in the lower St. Johns River and in the harbor. Much of this investigation will rely upon numerical modeling, and consequently field data are needed with which to calibrate and verify model results. The measurements taken during this project include water level (tide), salinity, current and salinity profiles, nearbed velocity and sediment concentration, and nearshore directional wave spectra. Data were collected using both fixed and mobile instruments.

2. Project Design and Execution

Fixed Instruments

Figure 1 provides a map of the project domain showing the schematic locations of the fixed instruments as required in the Scope of Work (SOW). These instruments included 1) a 'CTD' meter that measured conductivity, temperature, and water level (pressure) located near the Arlington Bridge (WL#1, CTD), 2) a pressure-based tide gauge located near Dames Point (WL#2), 3) a side-looking Acoustic Doppler Profiler (ADP) located across from the Mayport Naval Base (CP-SL), 4) a tide gauge located at the intersection of the ICW and Ft. George River (WL#3), and 5) a tide gauge (WL#4) and collocated Acoustic Doppler Current Profiler (ADCP) directional wave gauge installed in the Atlantic Ocean north of Ft. George River Inlet. After installation, the position of each fixed instrument was determined by a registered Professional Land Surveyor, and the results are presented in Figure 2. Details of the fixed instrument deployment, as executed, are provided in Table 1.

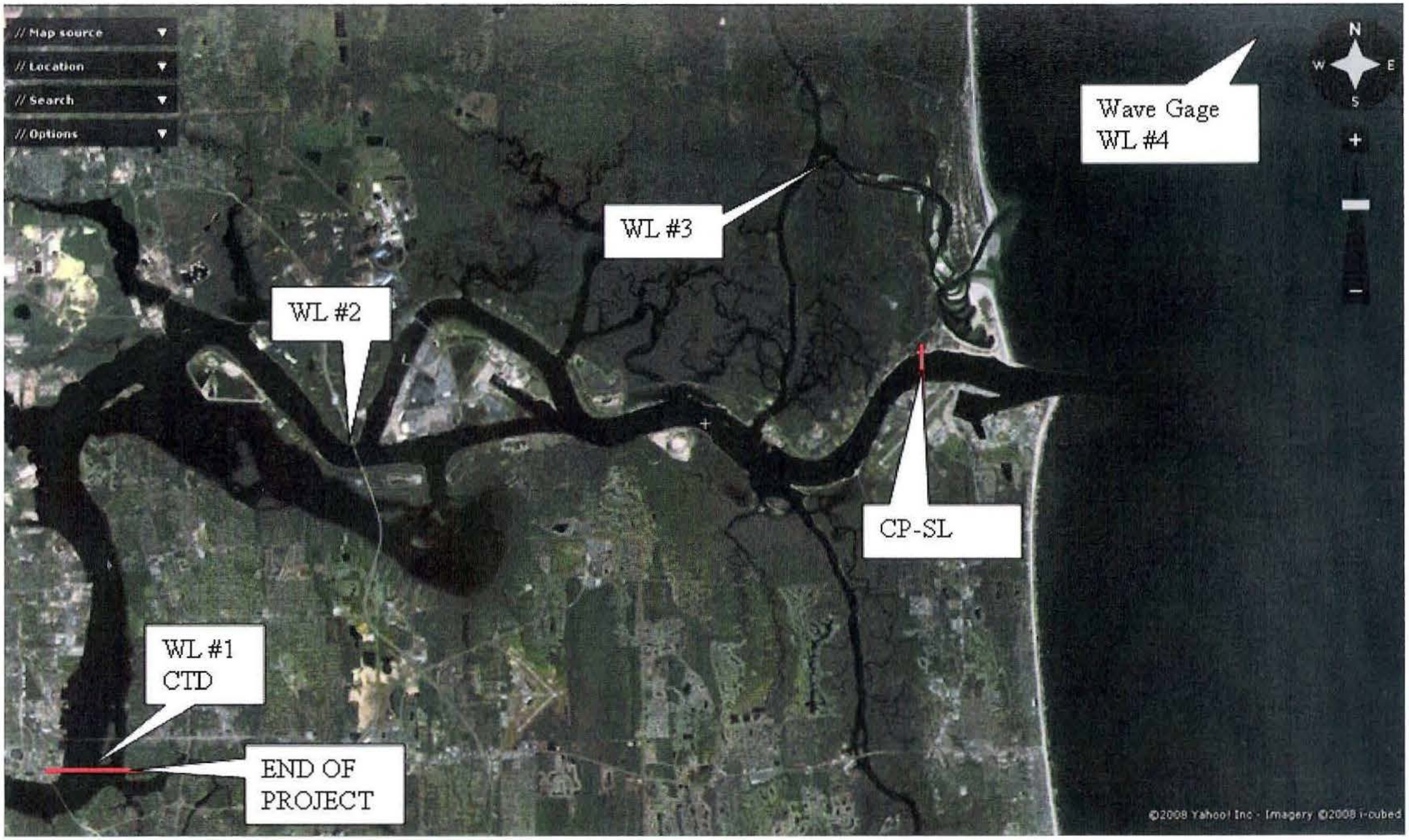
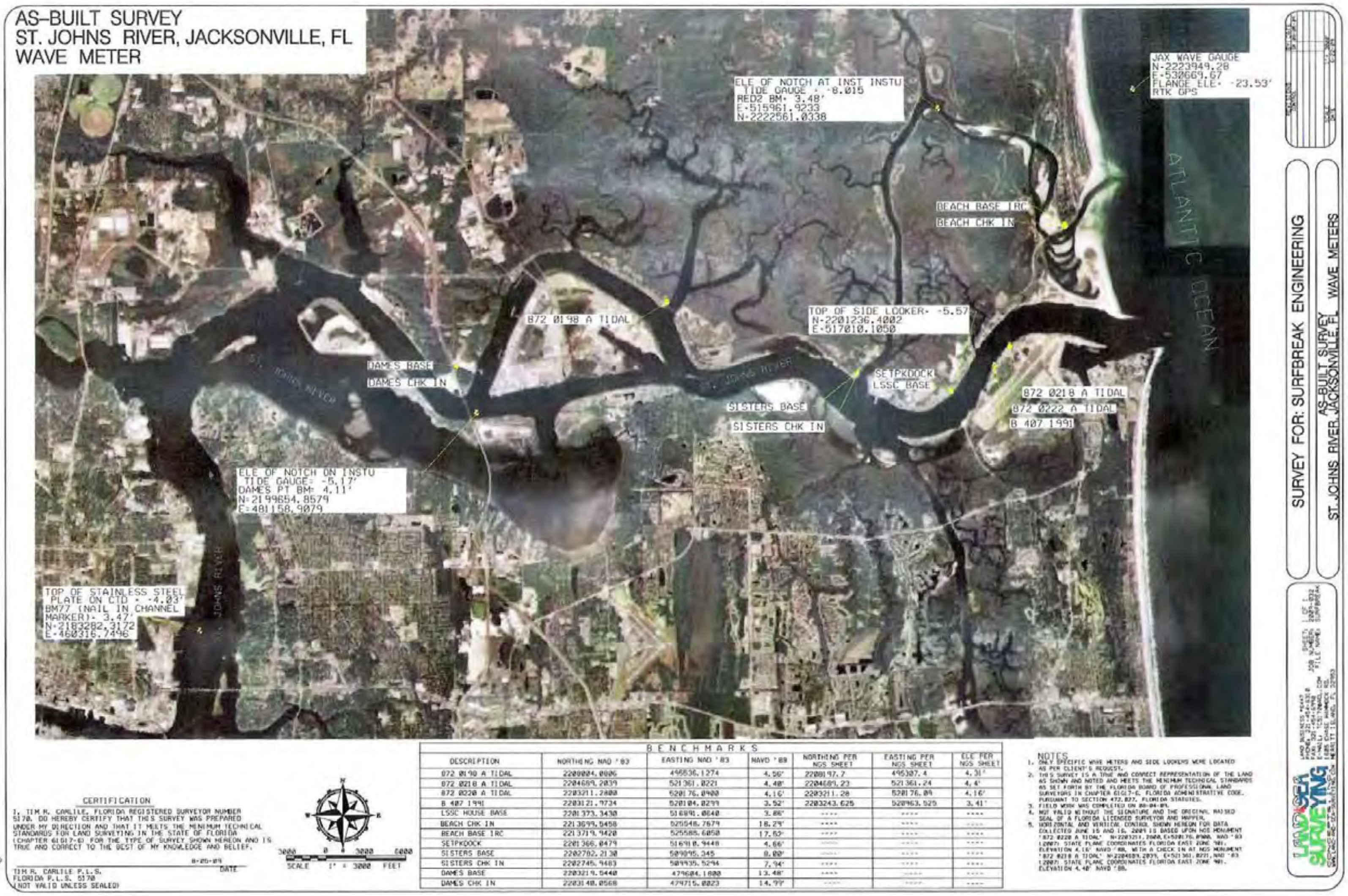


Figure 1 – Schematic map of Jacksonville Harbor data collection project, indicating the proposed locations of the fixed instruments.



BENCHMARKS

DESCRIPTION	NORTHING NAD '83	EASTING NAD '83	NAVD '88	NORTHING PER NGS SHEET	EASTING PER NGS SHEET	ELE PER NGS SHEET
872 0198 A TIDAL	2200004.0006	495536.1274	4.56'	2200197.7	495307.4	4.31'
872 0218 A TIDAL	2204689.2039	521361.0221	4.40'	2204689.23	521361.24	4.4'
872 0220 A TIDAL	2203211.2800	520176.0900	4.16'	2203211.20	520176.09	4.16'
B 407 1991	2203121.9734	520104.0299	3.52'	2203243.625	520963.525	3.41'
LSSC HOUSE BASE	2201373.3430	516891.0640	3.86'	****	****	****
BEACH CHK IN	2213699.5458	525548.7679	18.29'	****	****	****
BEACH BASE IRC	2213719.9420	525588.6050	17.62'	****	****	****
SETPKDOCK	2201366.0479	516910.9440	4.66'	****	****	****
SISTERS BASE	2202782.2130	509895.345	0.00'	****	****	****
SISTERS CHK IN	2202745.9483	509935.5294	7.94'	****	****	****
DAMES BASE	2203219.5440	479604.1800	13.40'	****	****	****
DAMES CHK IN	2203140.0568	479715.0023	14.99'	****	****	****

Figure 2 – Surveyor's map of project area showing actual locations of fixed instruments [map is provided on the data CD].

Table 1 – Fixed Instrument Deployment

Instrument (as denoted in SOW)	**Location**	**Make & Model**	**Parameter(s) Measured**	**Deployment Dates (2009)**
WL#1; CTD	Arlington Bridge (channel marker G77) N30° 20.338' W81° 37.250'	Seabird 26 CTD	conductivity, water temperature, density, tide elevation (pressure)	6/16 – 7/29
WL#2	Dames Point Turn (navigation aid) N30° 22.981' W81° 33.302'	In Situ, Inc. Level TROLL® 100	tide elevation (pressure)	6/16 – 7/29
CP-SL	Mayport/Sherman Cut (channel marker R18) N30° 23.268' W81° 26.481	Sontek, Inc. Argonaut 500kHz ADP-SL	cross-channel distribution of current speed and direction	6/15 – 7/29
WL#3	Intersection of Ft. George River & ICW (channel marker 2) N30° 26.785 W81° 26.696	In Situ, Inc. Level TROLL® 100	tide elevation (pressure)	4/28 – 7/29
WL#4	Offshore N30° 27.023 W81° 23.897	In Situ, Inc. Mini TROLL	tide elevation (pressure)	4/28 – 6/18 6/18 – 8/3
Wave Gauge	Offshore N30° 27.023 W81° 23.897	RD Instruments 1200 kHz Workhorse	vertical current profile, tide elevation (pressure), directional wave spectra	4/28 – 6/18 6/18 – 8/3
Barometer	Dry land N30° 18.897' W81° 27.990'	Onset Computer Corporation, HOBO Micro Station Logger	atmospheric pressure	4/28 – 8/3

Mobile Instruments

Two different types of mobile measurements were conducted using boat-mounted and boat-cast instruments, and the measurement scheme as dictated in the SOW is depicted in Figure 3. Firstly, an array of three instruments consisting of a CTD, an Acoustic Doppler Velocimeter (ADV), and a LISST (Laser In-Situ Scattering and Transmissometry) was cast and retrieved from a boat using an electric winch system. Each cast was made while at anchor at each of 21 stations along the St. Johns River, during both peak flood current and peak ebb current conditions. Also, a down-looking ADCP was mounted to the boat, and used to measure local vertical profiles of current. This component of the project is referred to as CP-M #1 - #4 in the SOW and in Figure 3. Photographs of the instruments and casting apparatus are provided in Figure 4. Details of the mobile casting work, as executed, are provided in Table 2.

A second boat that was equipped with a down-looking ADP was used to measure vertical current profiles as the boat slowly motored along cross-channel transects of the river. The locations of the ADP-transect work are also shown schematically in Figure 3. Profiles were measured during both peak ebb and peak flood currents. Details of the current profile transects, as executed, are provided in Table 3.

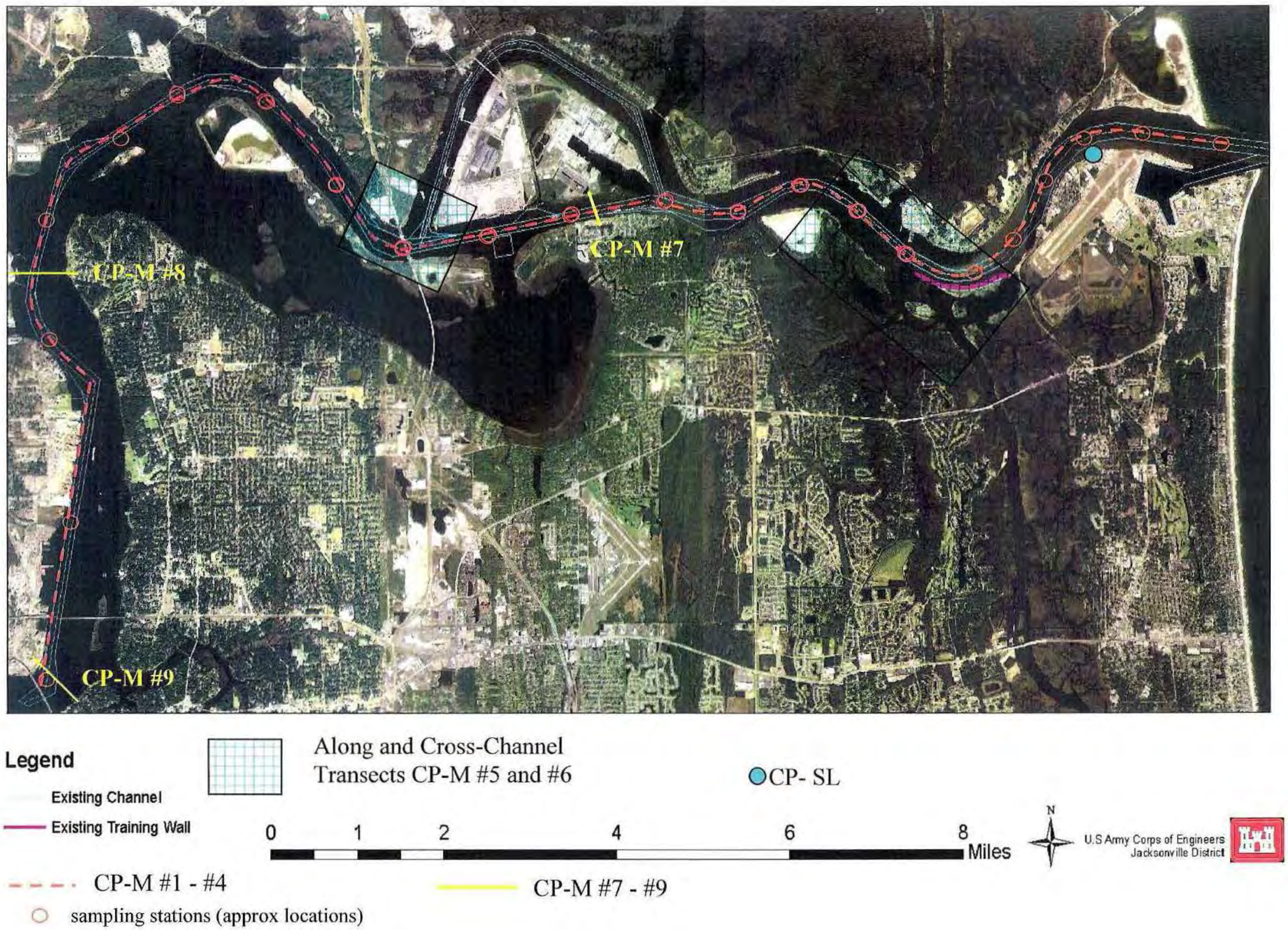
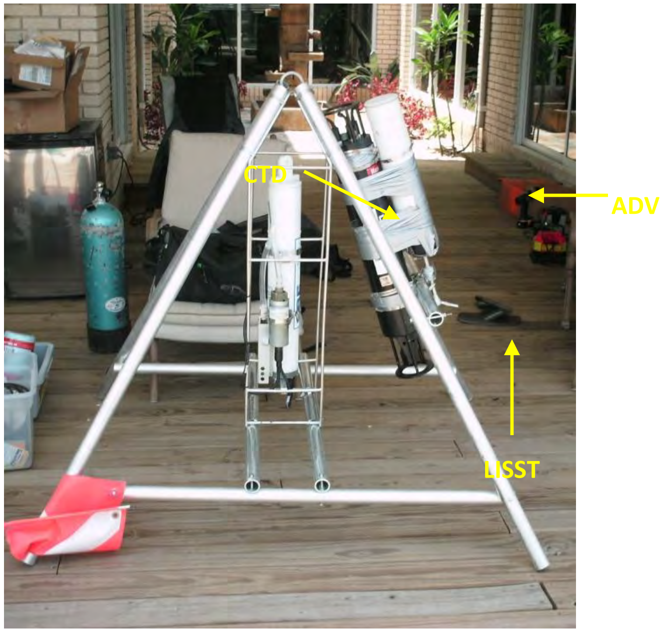


Figure 3 – Schematic map of current profiling transects and sampling locations for casting work.


CTD
ADV
LISST

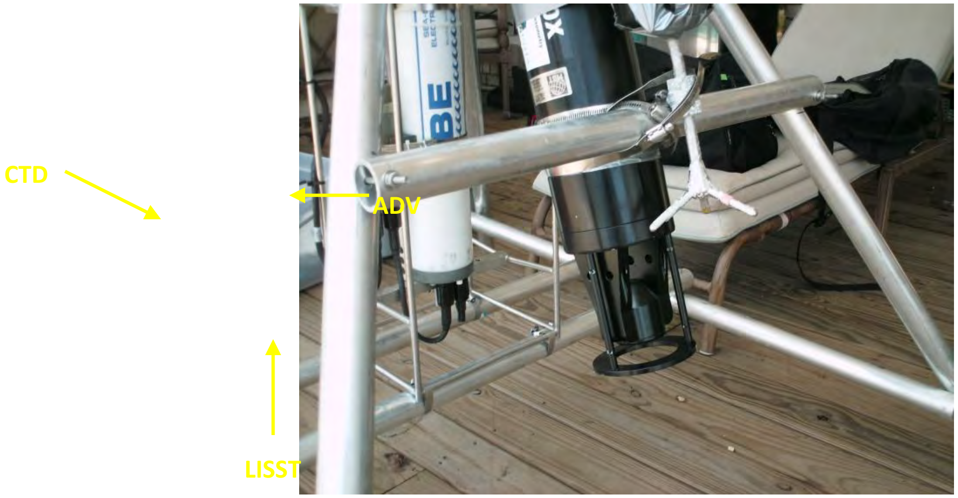

CTD
ADV
LISST

Figure 4 – Instruments, frame, and casting apparatus.

Table 2 – Mobile Casting Measurements & Current Profiles (CP-M #1-#4)

RD Instruments ADCP, Seabird 19 CTD, Sequoia LISST, and Sontek ADV

Cast Number	Station & Nearest Channel Marker	Lat/Long	Date	Time (LST)	Flow Condition
1	Station 1 – R10	N30^o 24.147’; W81^o 24.099’	6/17	07:19	Ebb
2	Station 2 – G11	N30^o 24.113’; W81^o 25.086’	6/17	07:44	Ebb
3	Station 3 - Ferry	N30^o 23.897’; W81^o 25.968’	6/17	08:11	Ebb
4	Station 4 – R20	N30^o 23.046’; W81^o 25.549’	6/17	08:30	Ebb
5	Station 5 – R24	N30^o 23.033’; W81^o 27.325’	6/17	08:58	Ebb
6	Station 7 – R34	N30^o 23.489’; W81^o 29.733’	6/17	09:22	Ebb
7	Station 9 – R42	N30^o 23.413’; W81^o 31.737’	6/17	09:45	Ebb
8	Station 11 – Day-Board	N30^o 23.032’; W81^o 33.701’	6/17	10:03	Ebb
9	Station 13 – G55	N30^o 24.509’; W81^o 35.271’	6/17	10:23	Ebb
10	Station 15 – G61	N30^o 23.950’; W81^o 37.189’	6/17	10:41	Ebb
11	Station 17 – G71	N30^o 22.338’; W81^o 37.617’	6/17	10:59	Ebb
12	Station 19 – G75	N30^o 20.797’; W81^o 37.156’	6/17	11:18	Ebb
13	Station 21 – R80	N30^o 18.897’; W81^o 37.818’	6/17	11:39	Ebb
14	Station 1 – R10	N30^o 24.139’; W81^o 24.158’	6/17	14:08	Flood
15	Station 2 – G11	N30^o 24.110’; W81^o 25.141’	6/17	14:27	Flood
16	Station 3 - Ferry	N30^o 23.791’; W81^o 26.039’	6/17	15:13	Flood
17	Station 4 – R20	N30^o 22.987’; W81^o 26.593’	6/17	15:26	Flood
18	Station 5 – R24	N30^o 22.996’; W81^o 27.297’	6/17	15:47	Flood
19	Station 6 – G25	N30^o 23.595’; W81^o 28.602’	6/17	16:07	Flood
20	Station 7 – R34	N30^o 23.458’; W81^o 29.852’	6/17	16:27	Flood
21	Station 8 – G37	N30^o 23.434’; W81^o 30.688’	6/17	16:41	Flood
22	Station 10 – Blount Is.	N30^o 23.077’; W81^o 33.034’	6/17	17:01	Flood
23	Station 11 – Day Board	N30^o 23.042’; W81^o 33.763’	6/17	17:20	Flood
24	Station 12 – G51	N30^o 23.817’; W81^o 34.420’	6/17	17:37	Flood
25	Station 9 – R42	N30^o 23.340’; W81^o 31.737’	6/17	17:59	Flood
26	Station 6 – G25	N30^o 23.561’; W81^o 28.486’	6/18	09:26	Ebb
27	Extra Station – G27	N30^o 23.558’; W81^o 29.050’	6/18	09:45	Ebb
28	Station 8 – G37	N30^o 23.428’; W81^o 30.672’	6/18	10:05	Ebb
29	Station 10 – Blount Is.	N30^o 23.053’; W81^o 33.049’	6/18	10:26	Ebb
30	Station 12 – G51	N30^o 23.791’; W81^o 34.392’	6/18	10:46	Ebb
31	Station 14 – G59	N30^o 24.384’; W81^o 36.147’	6/18	11:09	Ebb
32	Station 16 – G67	N30^o 23.024’; W81^o 37.609’	6/18	11:31	Ebb
33	Station 18 – Day Board	N30^o 21.531’; W81^o 36.990’	6/18	11:55	Ebb
34	Station 20 – G79	N30^o 19.293’; W81^o 37.454’	6/18	12:16	Ebb
35	Station 13 – G55	N30^o 24.445’; W81^o 35.185’	6/18	14:57	Flood
36	Station 14 – G59	N30^o 24.379’; W81^o 36.139’	6/18	15:17	Flood
37	Station 15 – G61	N30^o 23.830’; W81^o 37.1919’	6/18	15:37	Flood
38	Station 16 – G67	N30^o 23.015’; W81^o 37.191’	6/18	15:57	Flood
39	Station 17 –G71	N30^o 22.328’; W81^o 37.589’	6/18	16:23	Flood
40	Station 18 – Day Board	N30^o 21.573’; W81^o 36.967’	6/18	16:58	Flood

41	Station 19 – G75	N30° 20.798'; W81° 37.138'	6/18	17:19	Flood
42	Station 20 – G79	N30° 19.281'; W81° 37.459'	6/18	17:39	Flood
43	Station 21 – R80	N30° 18.902'; W81° 37.836'	6/18	17:56	Flood

Table 3 – Down-looking Current Profile Transects

Sontek River Surveyor 1500 kHz Acoustic Doppler Profiler

SOW Designation & Channel Marker	**Starting Location**	**Date (2009)**	**Time (LST)**	**Flow Condition**
CP-M #5 - R22	30.3839N,-81.4495W	6/16	12:52	Flood
CP-M #5 – G25	30.3952N,-81.4732W	6/16	13:24	Flood
CP-M #5 – G1	30.3817N,-81.4593W	6/16	13:52	Flood
CP-M #7	30.3932N,-81.5152W	6/16	14:10	Flood
CP-M #5 – R88	30.3907N,-81.4639W	6/16	15:15	Flood
CP-M #5 – G25	30.3949N,-81.4732W	6/16	15:23	Flood
CP-M #5 – R22	30.3836N,-81.4496W	6/16	15:35	Flood
CP-M #5 – R22	30.3838N,-81.4493W	6/17	07:33	Ebb
CP-M #5 – G1	30.3813N,-81.4589W	6/17	07:43	Ebb
CP-M #5 – R88	30.3908N,-81.4638W	6/17	08:10	Ebb
CP-M #5 – G25	30.3948N,-81.4725W	6/17	08:17	Ebb
CP-M #7	30.3918N,-81.5214W	6/17	08:33	Ebb
CP-M #6 – G45	30.3888N,-81.5426W	6/17	08:42	Ebb
CP-M #6 – G1	30.3891N,-81.5520W	6/17	08:52	Ebb
CP-M #6 – R48	30.3894N,-81.5630W	6/17	09:07	Ebb
CP-M #8	30.3762N,-81.6322W	6/17	10:38	Ebb
CP-M #9	30.3192N,-81.6275W	6/17	11:09	Ebb
CP-M #5 – R22	30.3839N,-81.4496W	6/17	14:12	Flood
CP-M #5 – G1	30.3800N,-81.4543W	6/17	14:22	Flood
CP-M #5 – R88	30.3910N,-81.4638W	6/17	14:39	Flood
CP-M #5 – G25	30.3949N,-81.4727W	6/17	14:48	Flood
CP-M #7	30.3919N,-81.5216W	6/17	15:02	Flood
CP-M #6 – G45	30.3888N,-81.5424W	6/17	15:10	Flood
CP-M #6 – G1	30.3892N,-81.5520W	6/17	15:19	Flood
CP-M #6 – R48	30.3893N,-81.5629W	6/17	15:26	Flood
CP-M #8	30.3760N,-81.6325W	6/17	16:38	Flood
CP-M #9	30.3190N,-81.6275W	6/17	17:04	Flood

3. Log of Activities

April 22 – Notice To Proceed received.

April 28 – Barometer, WL#3, WL#4, and ADCP wave gauge installed.

May1 – Planning meeting held.

June 11 – Pre-deployment conference call.

June 15 – Boat work mobilized. ADP sidelooker (CP-SL) installed.

June 16 – WL#1/CTD, WL#2 installed; ADP transects started.

June 17 – ADP transects completed; Casting work started.

June 18 – Casting work completed; WL#4 and ADCP wave gauge swapped.

July 29 – WL#1/CTD, WL#2, ADP-SL, and WL#3 retrieved.

August 3 – WL#4, ADCP wave gauge, and barometer retrieved.

August 21 – Final data disk delivered.

4. Overview of Data Collected

All data collected during this project have been archived on a single CD disk labeled:

Data Disk

Jacksonville Harbor Navigation Project

Field Data Collection

USACE, Jacksonville District

August 19, 2009 **CD 1 of 1**

The files archived include 1) all raw data collected (in binary format), 2) processed data that have been subjected to editing and preliminary quality checks (in space-delimited ASCII format), 3) header files containing all instrument-specific information required by the Scope of Work, and 4) example plots of each type of data collected. A brief summary for each instrument is provided below.

Barometric Pressure

Measurements of atmospheric pressure were taken using a HOBO Micro Station Self-recording barometer manufactured by the Onset Computer Corporation. The location of the barometer was N30° 18.897', W81° 27.990'. The processed data are plotted in Figure 5 below.

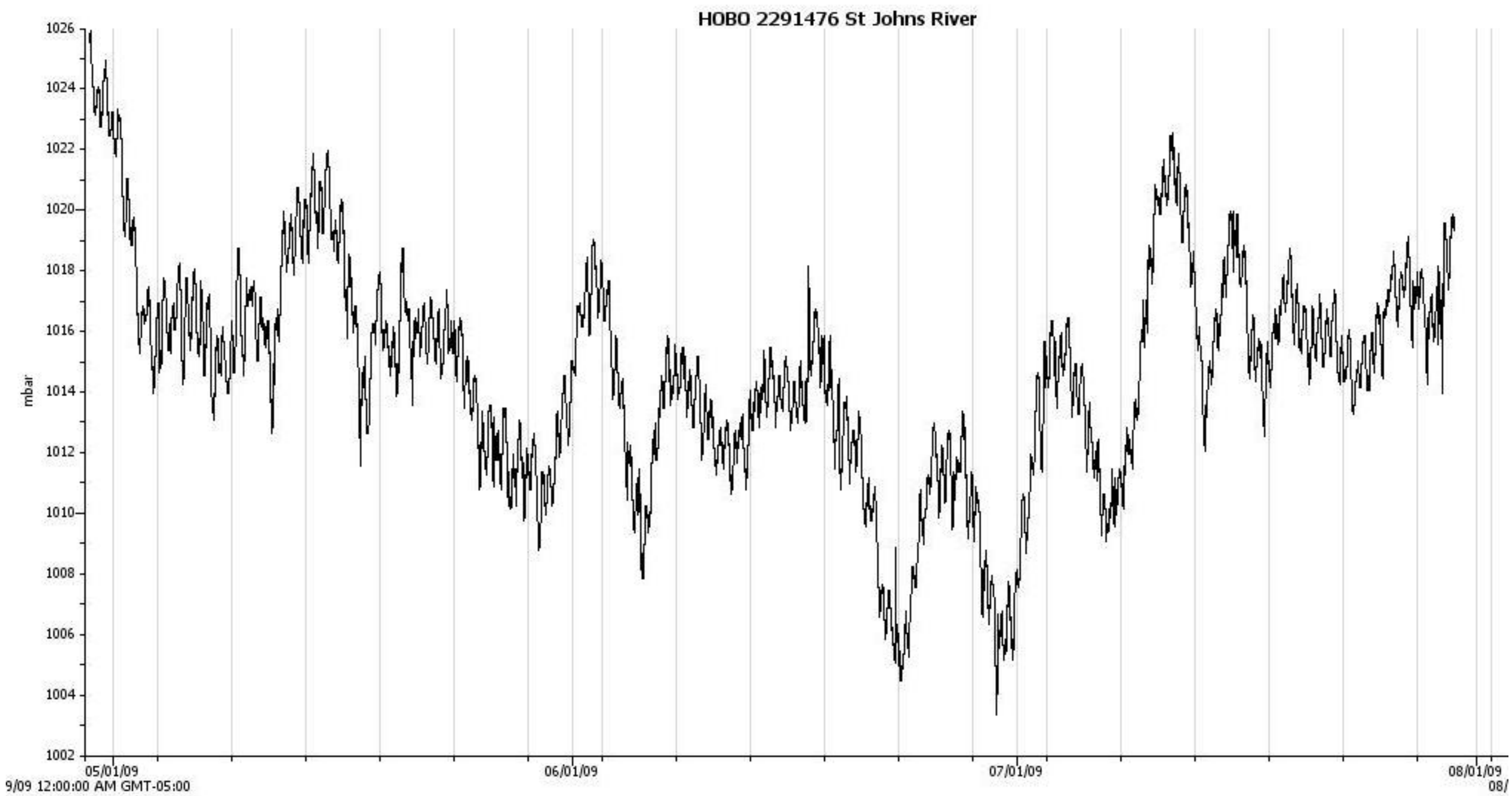


Figure 5 – Plot of barometric pressure recorded April 28 – August 3, 2009.

WL#1/ CTD

Measurements of conductivity, temperature, salinity, and pressure were taken using a Seabird 26 self-recording CTD. Specifics of the instrument location are: Gauge Elevation = -4.03' NAVD88; Northing = 2183282.3172' NAD83; Easting = 460316.7496' NAD83; N30° 20' 15.71478", W81° 37' 15.01303". The processed data are plotted in Figure 6a below.

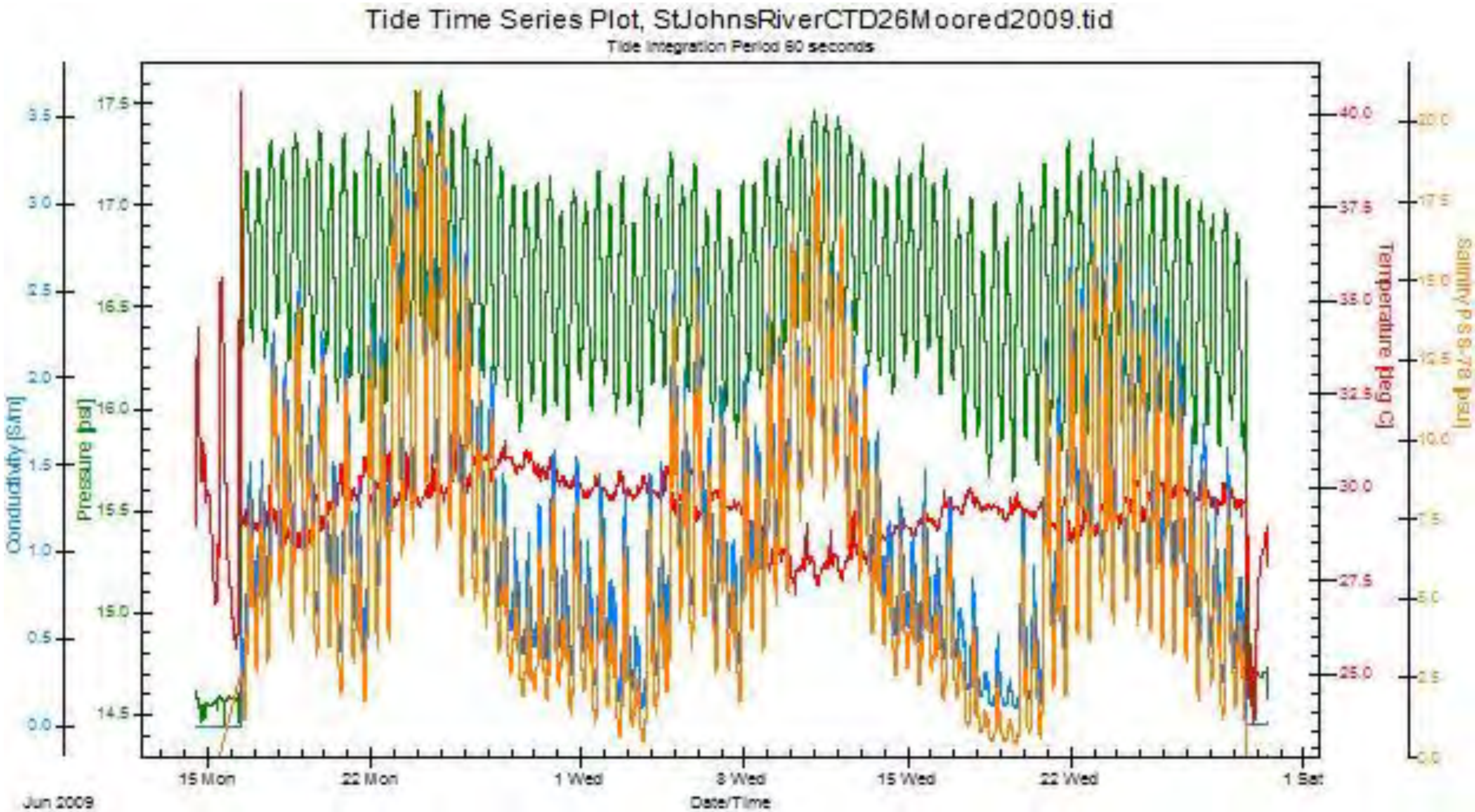


Figure 6a – Plot of all data collected by WL#1/CTD.

The pressure data recorded by the CTD were converted to water level elevation by 1) subtracting atmospheric pressure as measured by the barometer, 2) multiplying by an assumed water density of 10,035 N/m^3, and 3) adjusting by the surveyed height of the instrument. A plot of these results is provided in Figure 6b.

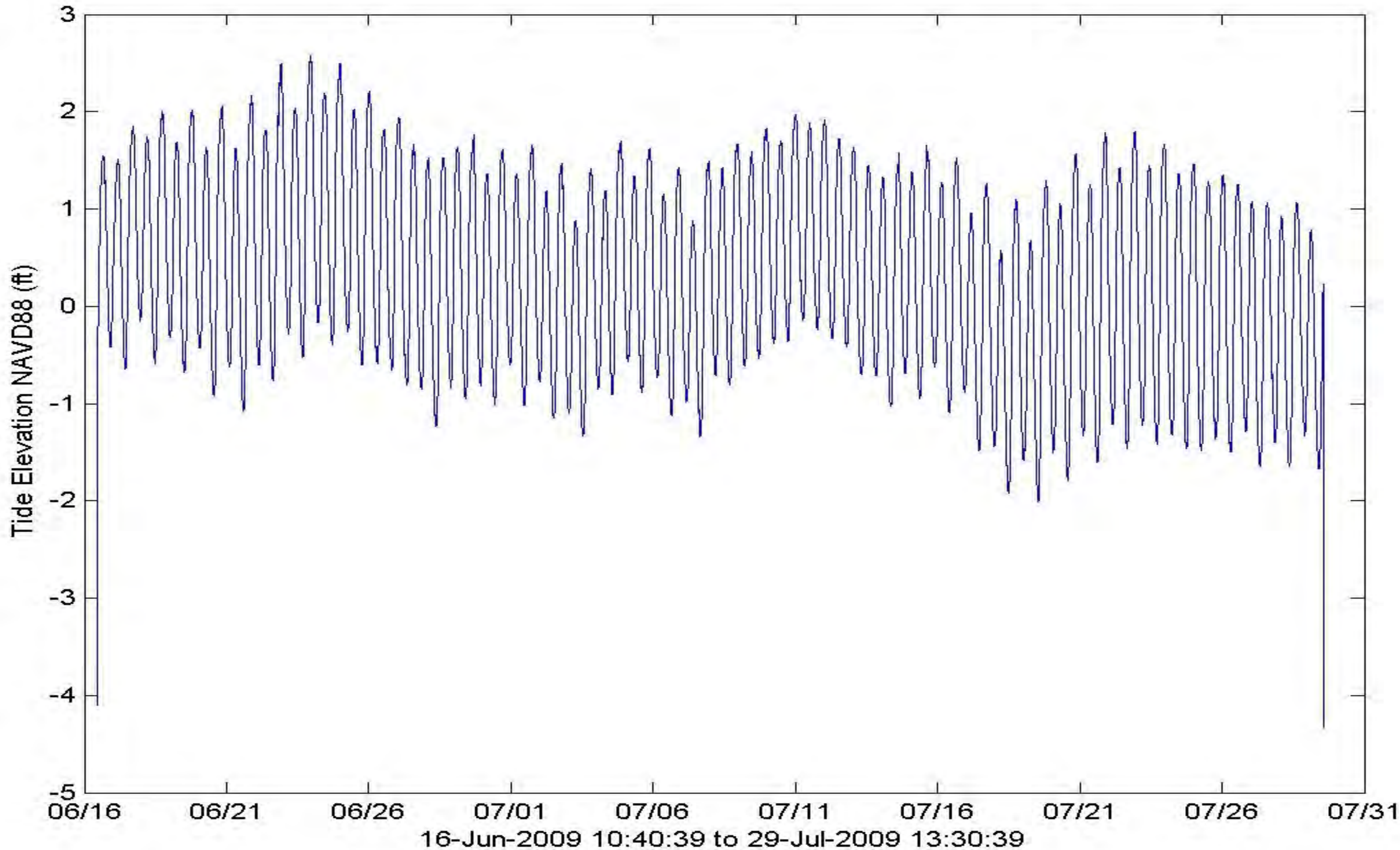


Figure 6b – WL#1/CTD pressure data converted to tide elevation (ft) relative to NAVD88.

WL#2

Measurements of subsurface pressure were taken using a ‘Level TROLL® 100’ self-recording pressure transducer, manufactured by In Situ, Inc.. The instrument was located at: Gauge Elevation = -5.17' NAVD88; Northing = 2199654.8579' NAD83; Easting = 481158.9079' NAD83; N30^{o} 22' 58.84145", W81^{o} 33' 18.09147". The pressure data were converted to water level elevation by 1) subtracting atmospheric pressure as measured by the barometer, 2) multiplying by an assumed water density of 10,035 N/m^3, and 3) adjusting by the surveyed height of the instrument. A plot of these results is provided in Figure 7.

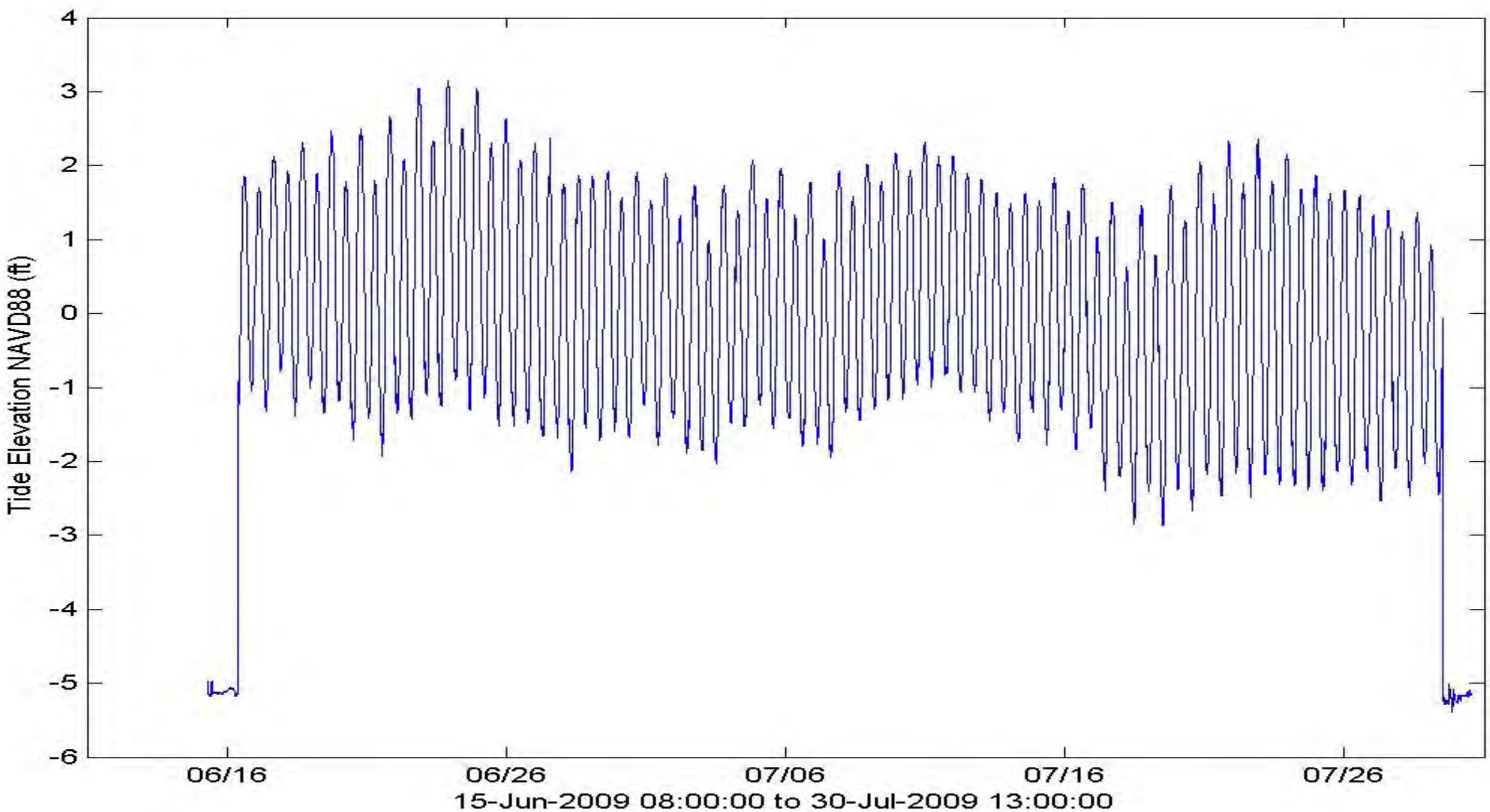


Figure 7 – WL#2 pressure data converted to tide elevation (ft) relative to NAVD88.

CP-SL (Side-Looking ADP)

Horizontal profiles of current speed and direction were taken using a 500kHz Argonaut Side-looking Acoustic Doppler Profiler manufactured by Sontek, Inc.. The instrument was strapped to a piling of a private dock located at: N30 23.274', W81 26.478'; Elevation - -5.57 ft NAVD88. A sample plot of these results is presented in Figure 8.

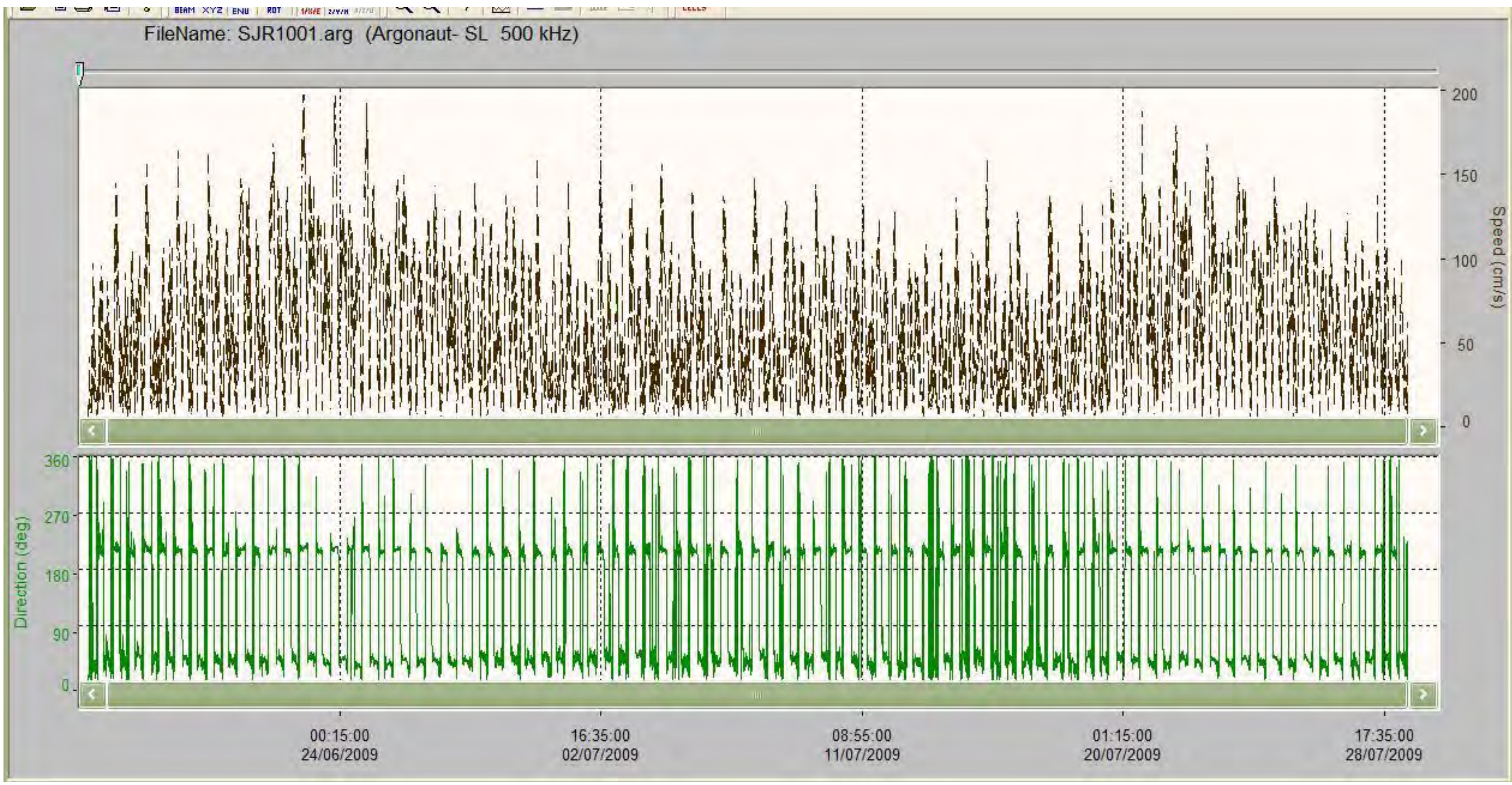


Figure 8 – Plot of current speed and direction at a distance of 50-60m from the Side-looking ADP.

WL#3

Measurements of subsurface pressure were taken using a 'Level TROLL® 100' self-recording pressure transducer, manufactured by In Situ, Inc.. The instrument was located at: Gauge Elevation = -8.015' NAVD88; Northing = 2222561.0338' NAD83; Easting = 515961.9233' NAD83; N30° 26' 47.09184", W81° 26' 41.78237". The pressure data were converted to water level elevation by 1) subtracting atmospheric pressure as measured by the barometer, 2) multiplying by an assumed water density of 10,035 N/m^3, and 3) adjusting by the surveyed height of the instrument. A plot of these results is provided in Figure 9.

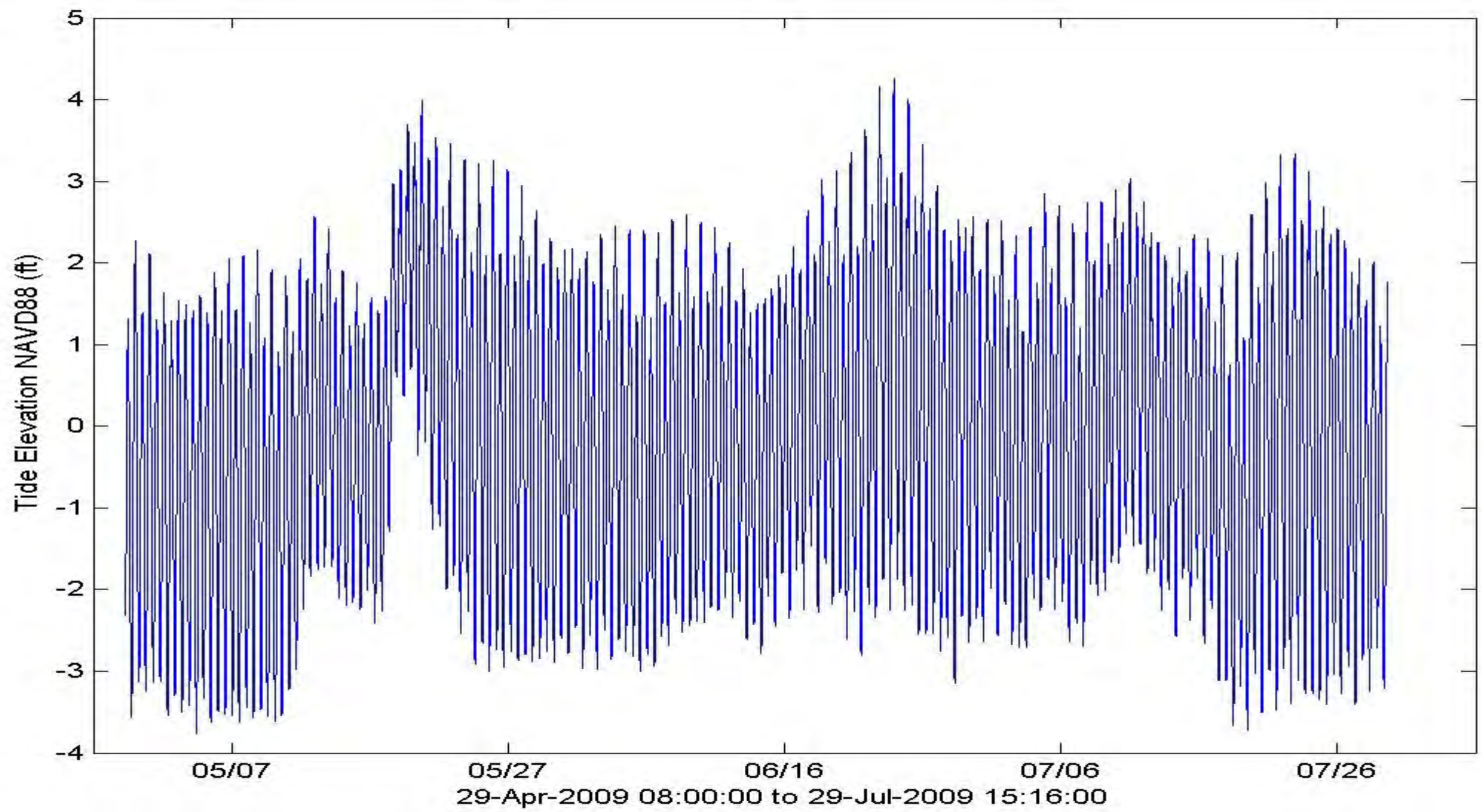


Figure 9 – WL#3 pressure data converted to tide elevation (ft) relative to NAVD88.

WL#4

Measurements of subsurface pressure were taken using a ‘Mini TROLL®‘ self-recording pressure transducer, manufactured by In Situ, Inc.. The instrument was located at: Gauge Elevation = -22.23' NAVD88; Northing = 2223949.28' NAD83; Easting = 530669.67' NAD83; N30 27' 1.37587", W81 23' 53.81340". It was deployed on the April 28th, swapped on June 18th, and retrieved on August 3rd. The pressure data were converted to water level elevation by 1) subtracting atmospheric pressure as measured by the barometer, 2) multiplying by an assumed water density of 10,035 N/m^3, and 3) adjusting by the surveyed height of the instrument. A plot of these results is provided in Figure 10a & 10b.

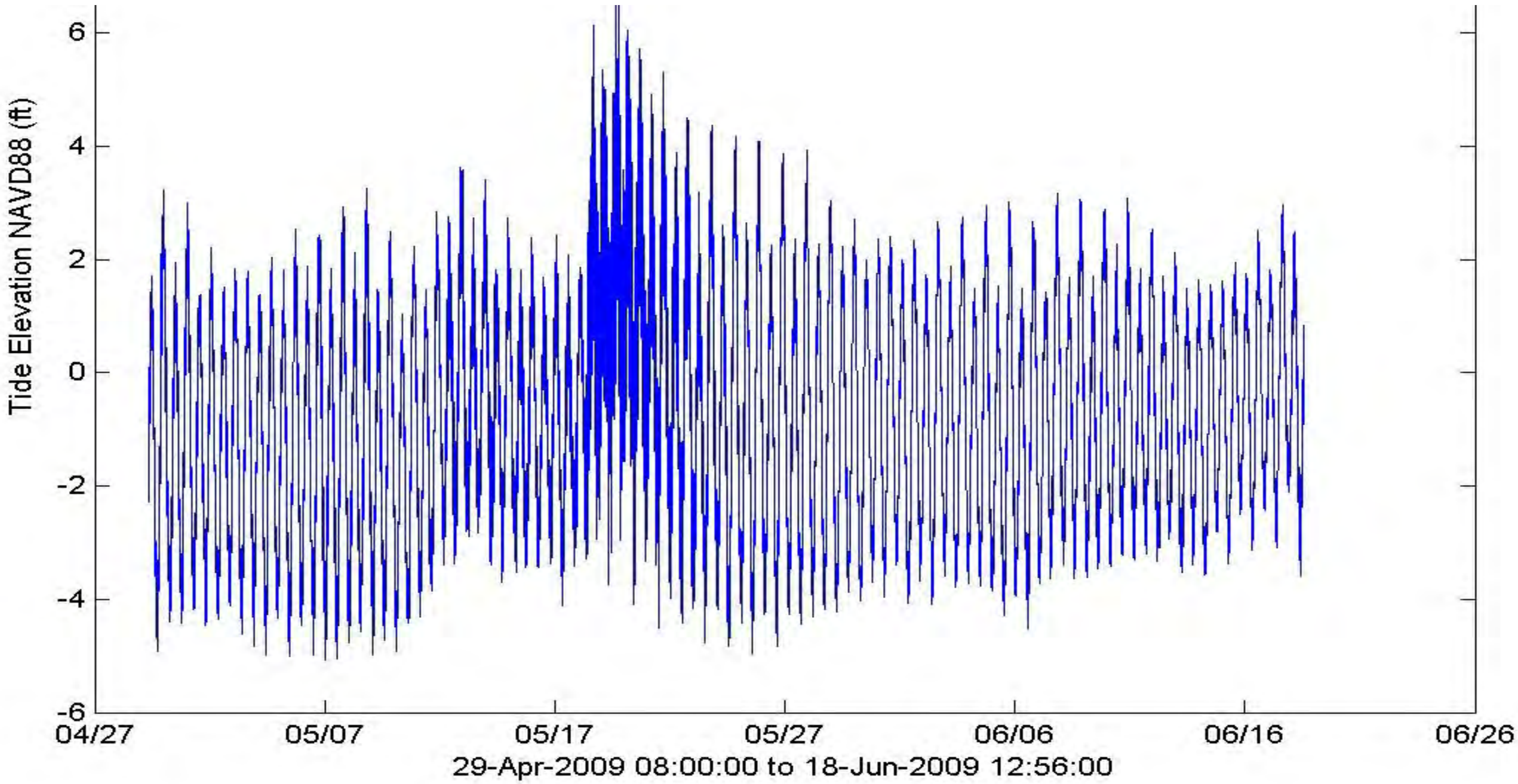


Figure 10a - WL#4 pressure data converted to tide elevation (ft) relative to NAVD88. First deployment.

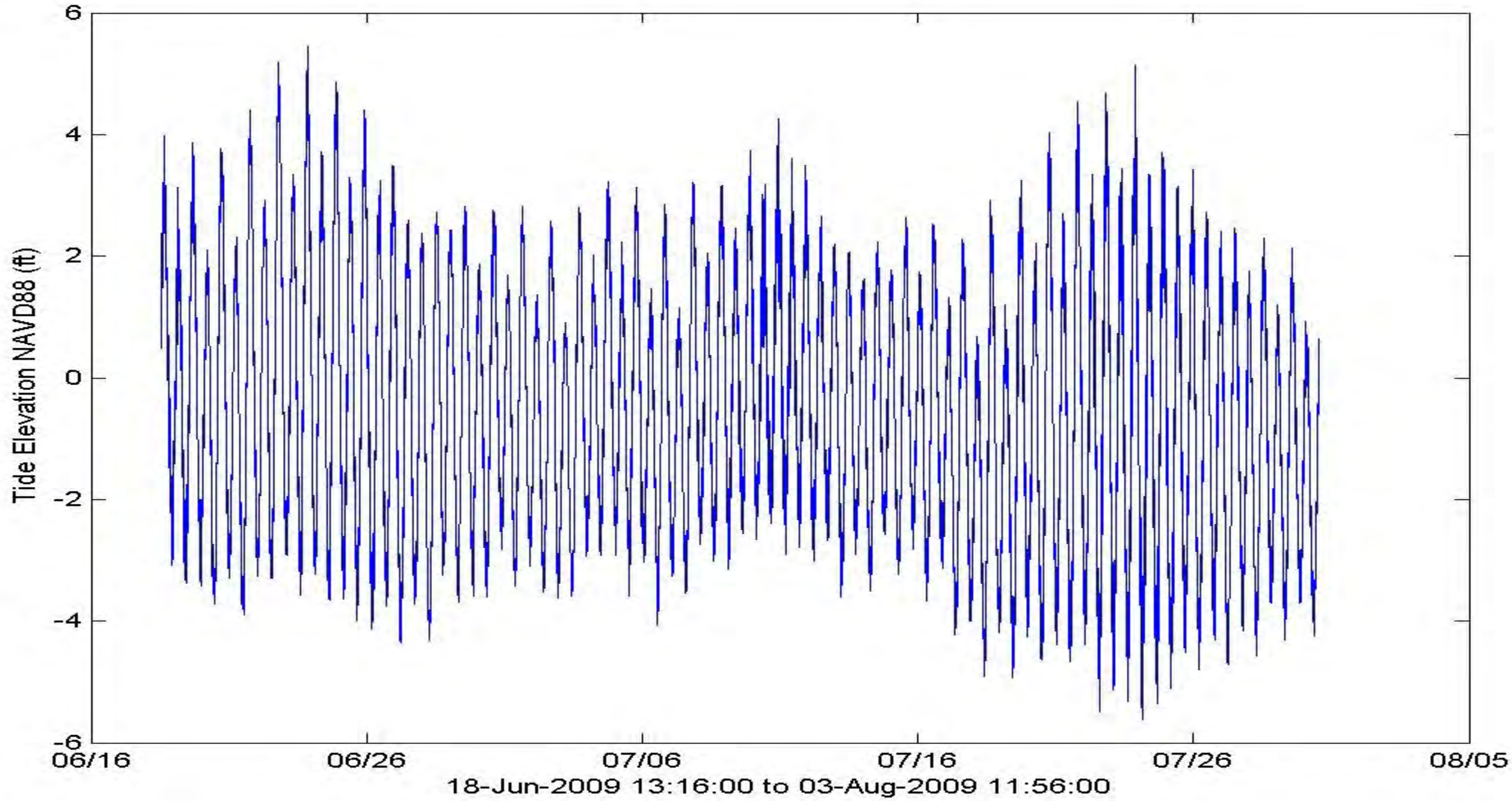


Figure 10b - WL#4 pressure data converted to tide elevation (ft) relative to NAVD88. Second deployment.

Offshore Wave Gauge

These measurements of water level, current profile, and directional wave spectra were taken using a 1200 kHz Workhorse Acoustic Doppler Current Profiler manufactured by RD Instruments, Inc. The ADCP was collocated with WL#4: Pressure Sensor Elevation = -22.23' NAVD88; Northing = 2223949.28' NAD83; Easting = 530669.67' NAD83; N30 27' 1.37587", W81 23' 53.81340". It was deployed on the April 28th, swapped on June 18th, and retrieved on August 3rd. Results are plotted in Figures 11a & b.

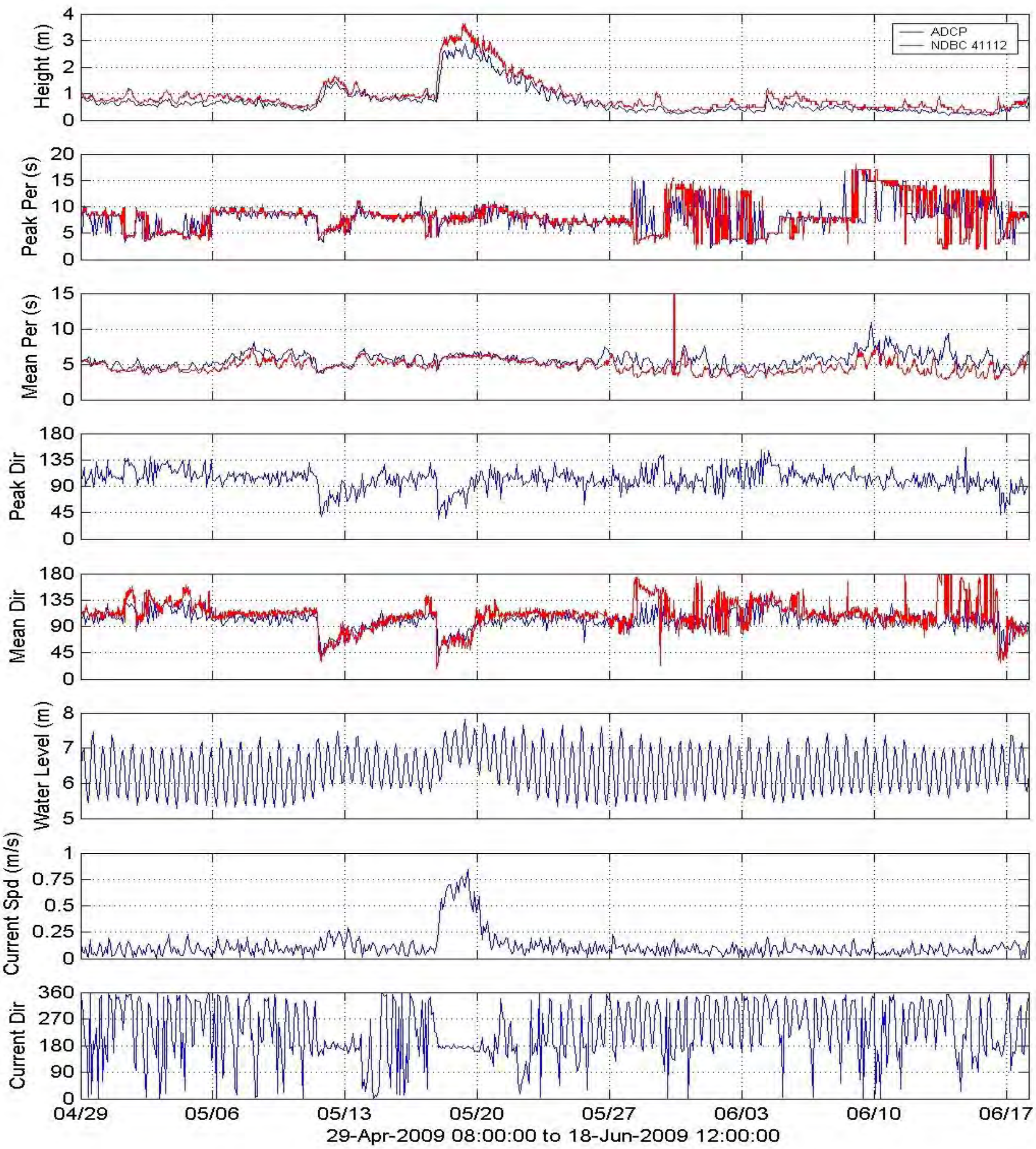


Figure 11a – Plot of ADCP wave gauge data. First deployment.

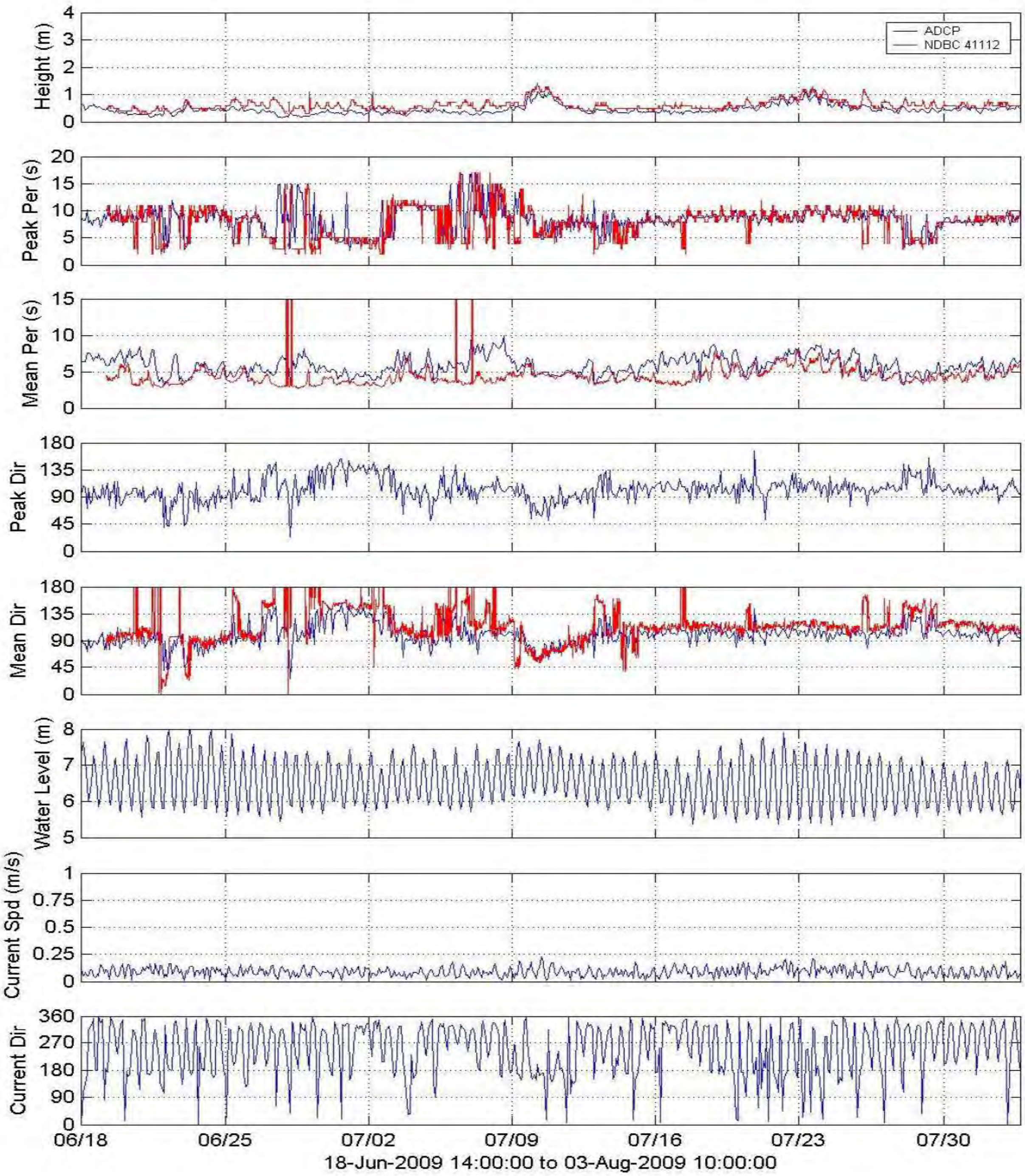


Figure 11b – Plot of ADCP wave gauge data. Second deployment.

Casting Boat ADCP

Vertical profiles of current speed and direction were measured from the casting boat while at anchor, using a 1200 kHz Workhorse Acoustic Doppler Current Profiler manufactured by RD Instruments, Inc.. The instrument was mounted to the stern of the boat, looking down through the water column. In all, 43 casts were made, and an ADCP file accompanies each cast. The position of the boat during each cast is supplied in the header files contained in the CD, as well as in Table 2. Summary plots of the current profiles measured on June 17th are presented in Figure 12a & b, and those measured on June 18th are presented in Figure 13a & b.

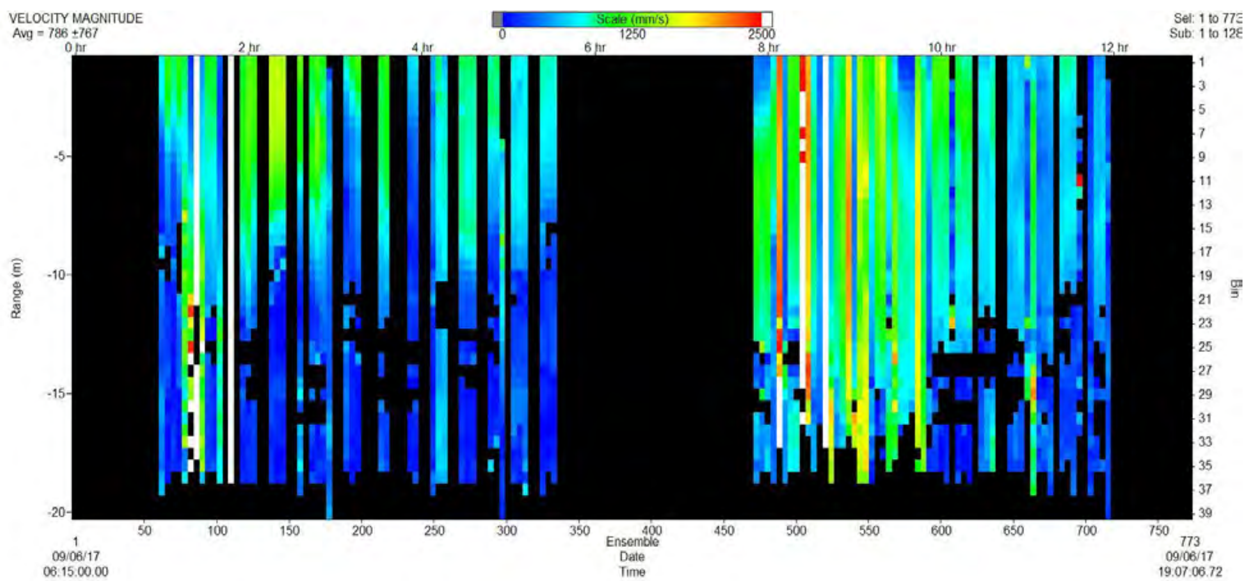


Figure 12a – Profiles of current speed measured during casting on June 17th.

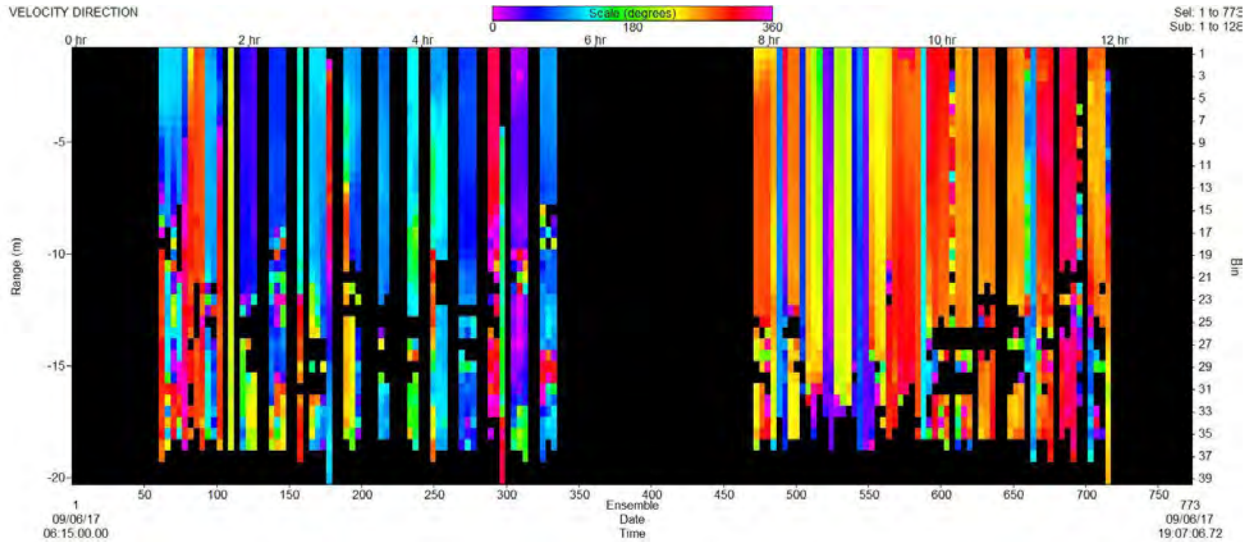


Figure 12b – Profiles of current direction measured during casting on June 17th. Cool colors are ebb conditions, warm colors are flood conditions. Directions are to-which water is flowing.

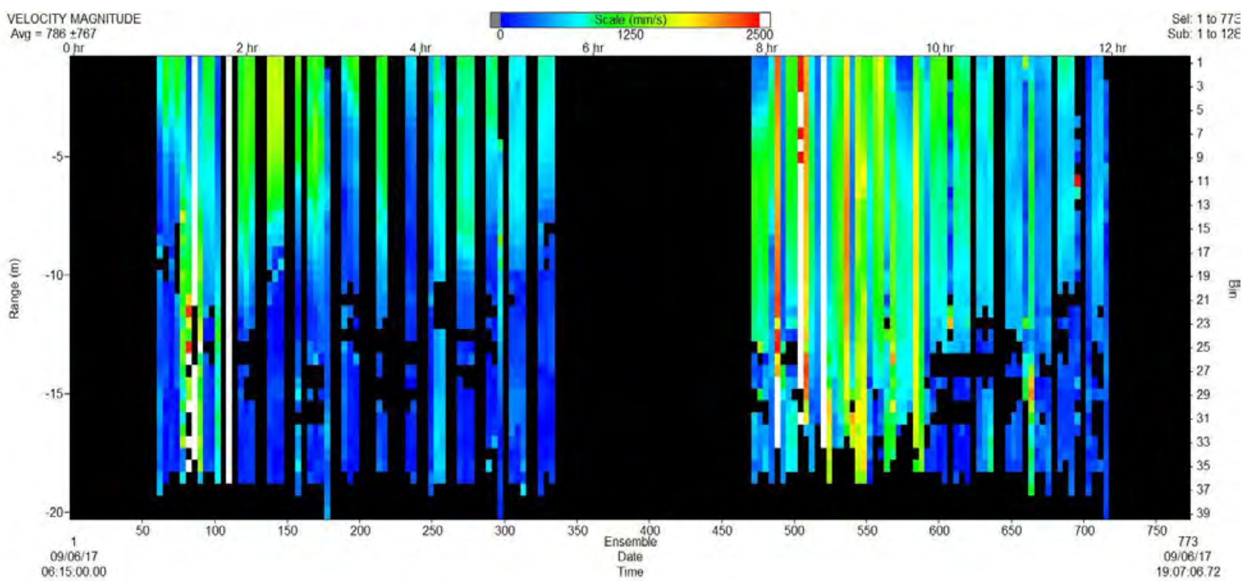


Figure 13a – Profiles of current speed measured during casting on June 18th.

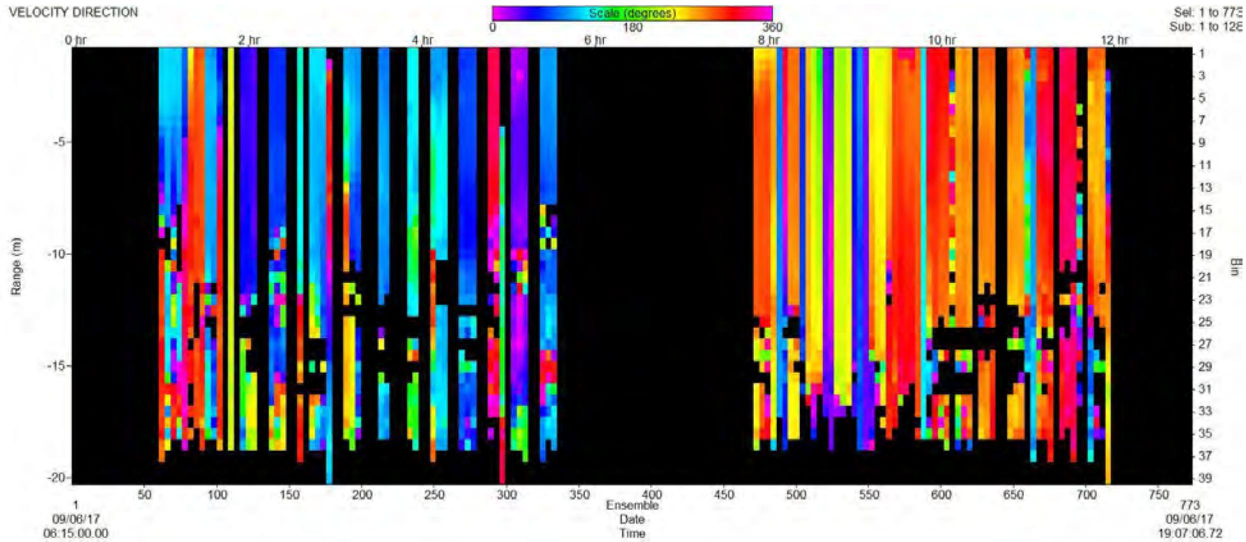


Figure 13b – Profiles of current direction measured during casting on June 18th. Cool colors are ebb conditions, warm colors are flood conditions. Directions are to-which water is flowing.

Casting Boat CTD

Vertical profiles of conductivity, salinity, temperature, and density were measured at each casting station using a Seabird 19 self-recording CTD. The location of the anchored boat during each cast is provided in Table 2. Sample plots of the CTD profiles taken at Channel Marker R10 (i.e. the station closest to the river mouth) are presented in Figure 14 under ebb conditions, and Figure 15 under flood conditions.

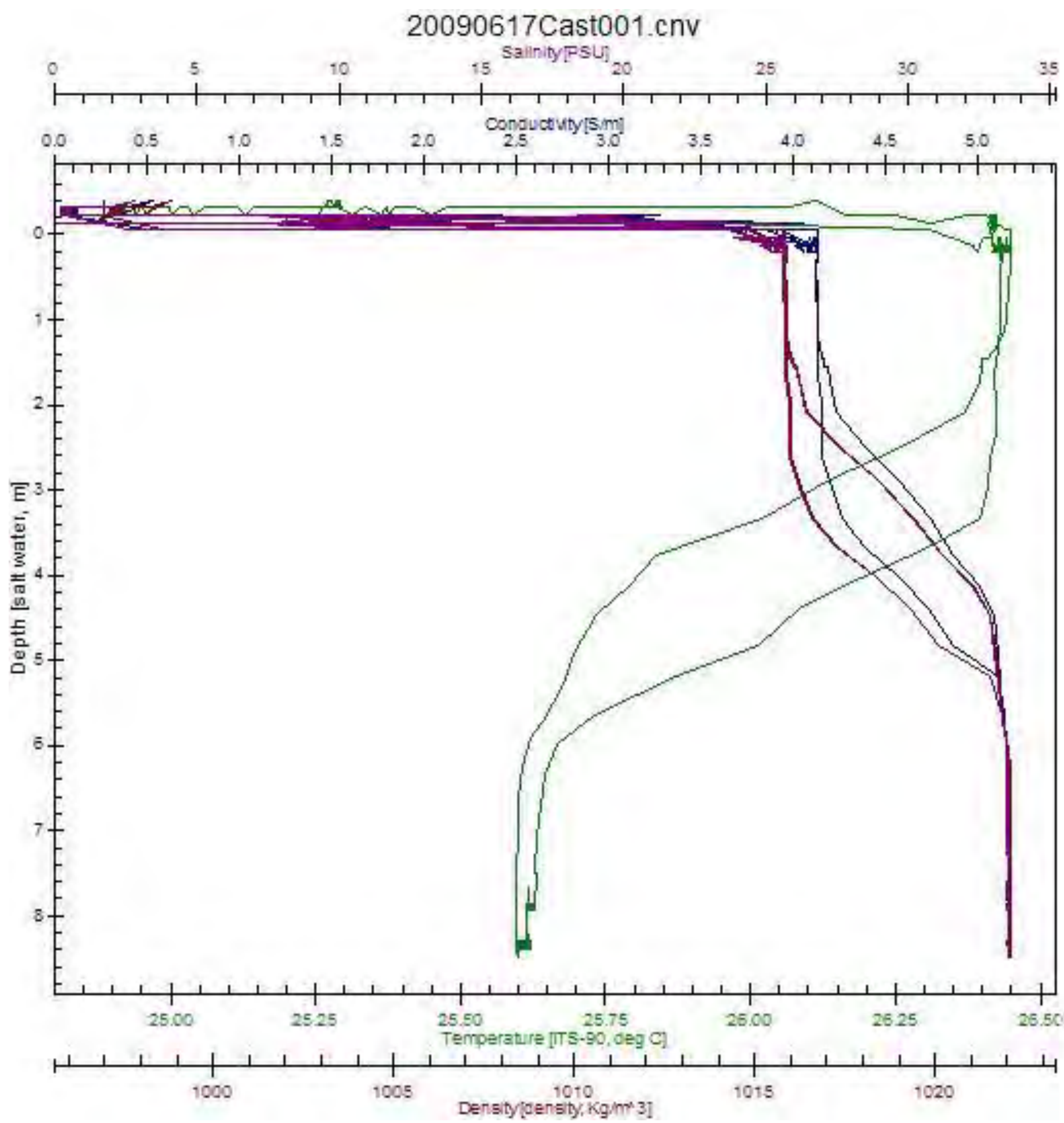


Figure 14 – CTD casting results at Channel Marker #R10 during ebb conditions on September 17th.

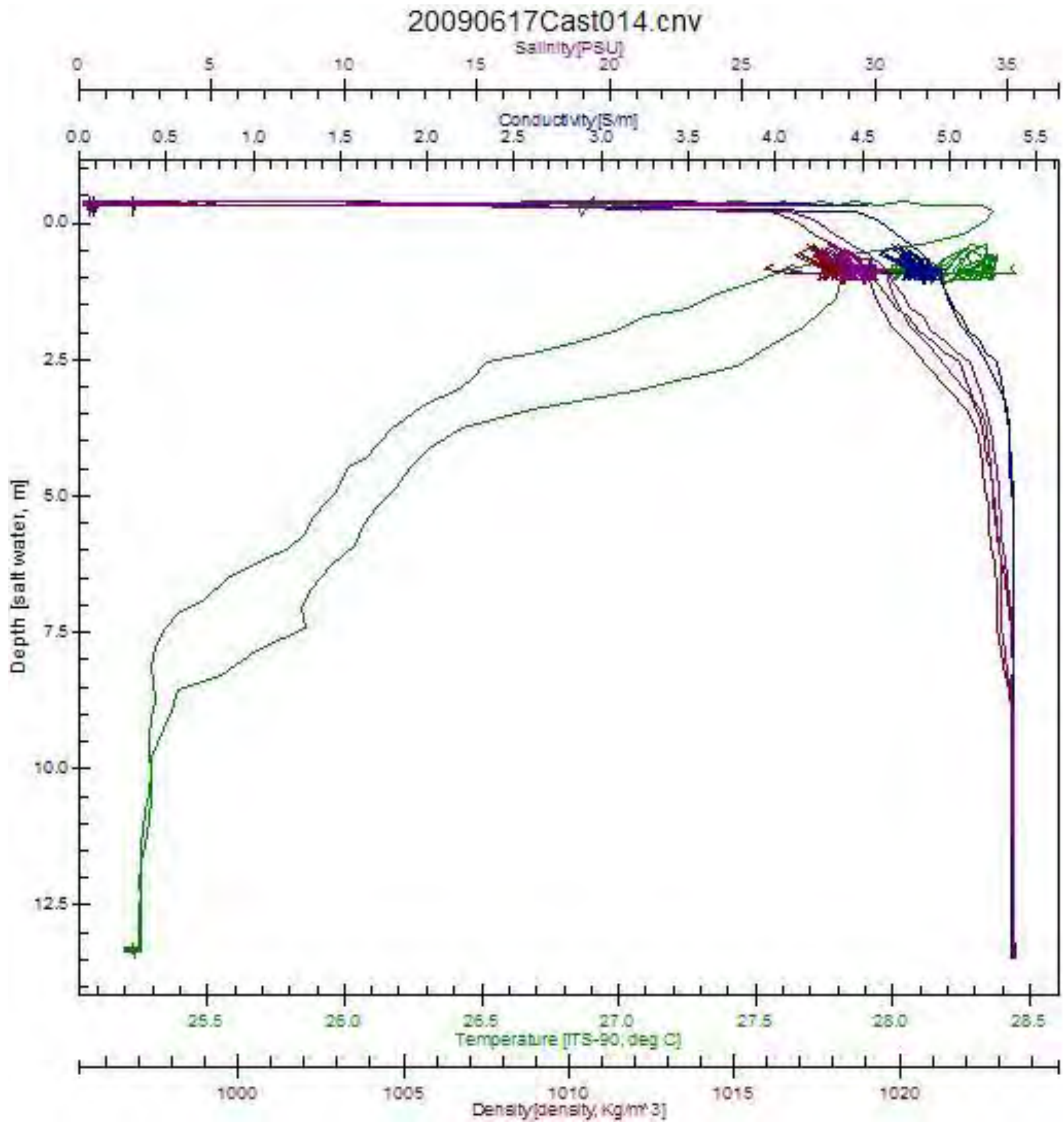


Figure 15 – CTD casting results at Channel Marker #R10 during flood conditions on September 17th.

Casting Boat ADV

In order to ensure that accurate measurements of current speed were acquired near the bed in support of the LISST measurements, an Acoustic Doppler Velocimeter, manufactured by Sontek, Inc. was cast along with the CTD and LISST. The location of the anchored boat during each cast is provided in Table 2. A plot of the entire ADV record for June 17th is presented in Figure 16, and a plot for June 18th is presented in Figure 17. The segments of the record during which the ADV was collecting data on the river bottom are identified as those times during which the pressure is at a steady peak (i.e. the pressure recorded while the array sat on the bottom) and the current speed is quasi-steady. These times (43 in all) have been clipped from the record and are archived on the CD.

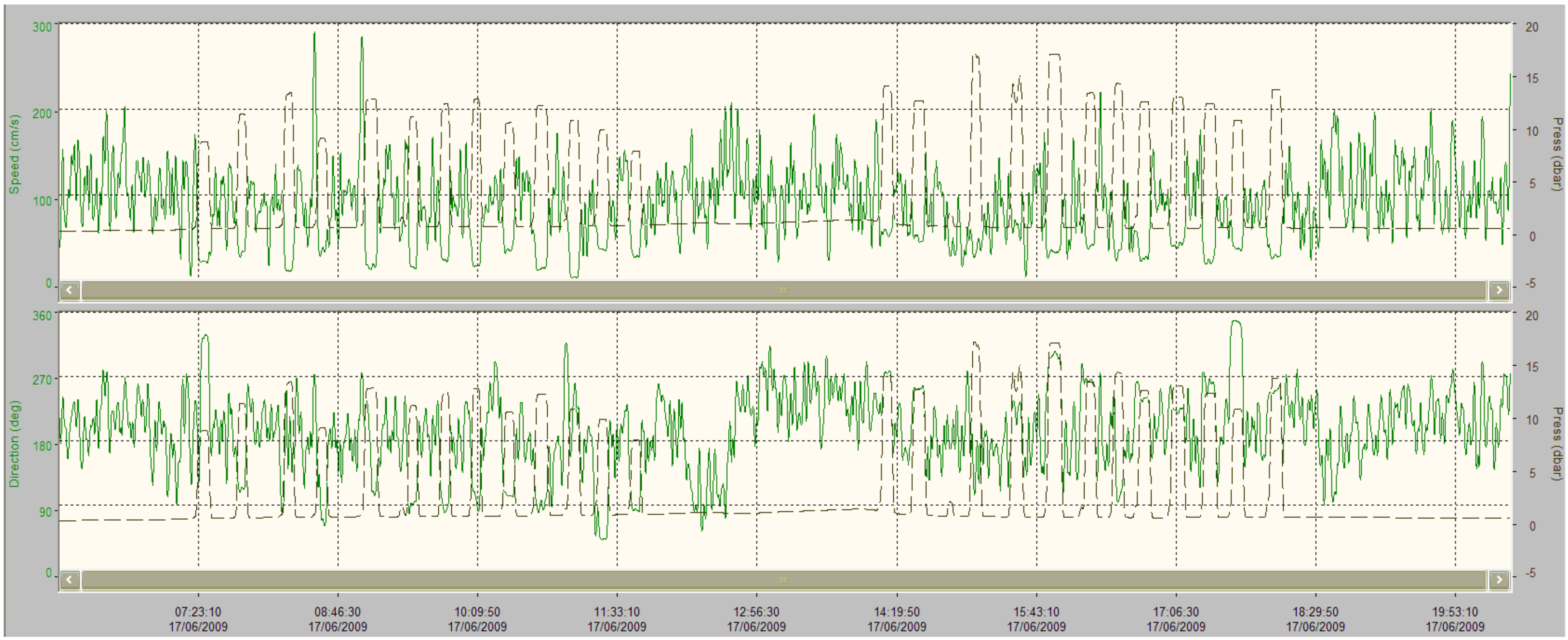


Figure 16 – Entire time series of ADV measurements taken on June 17th.

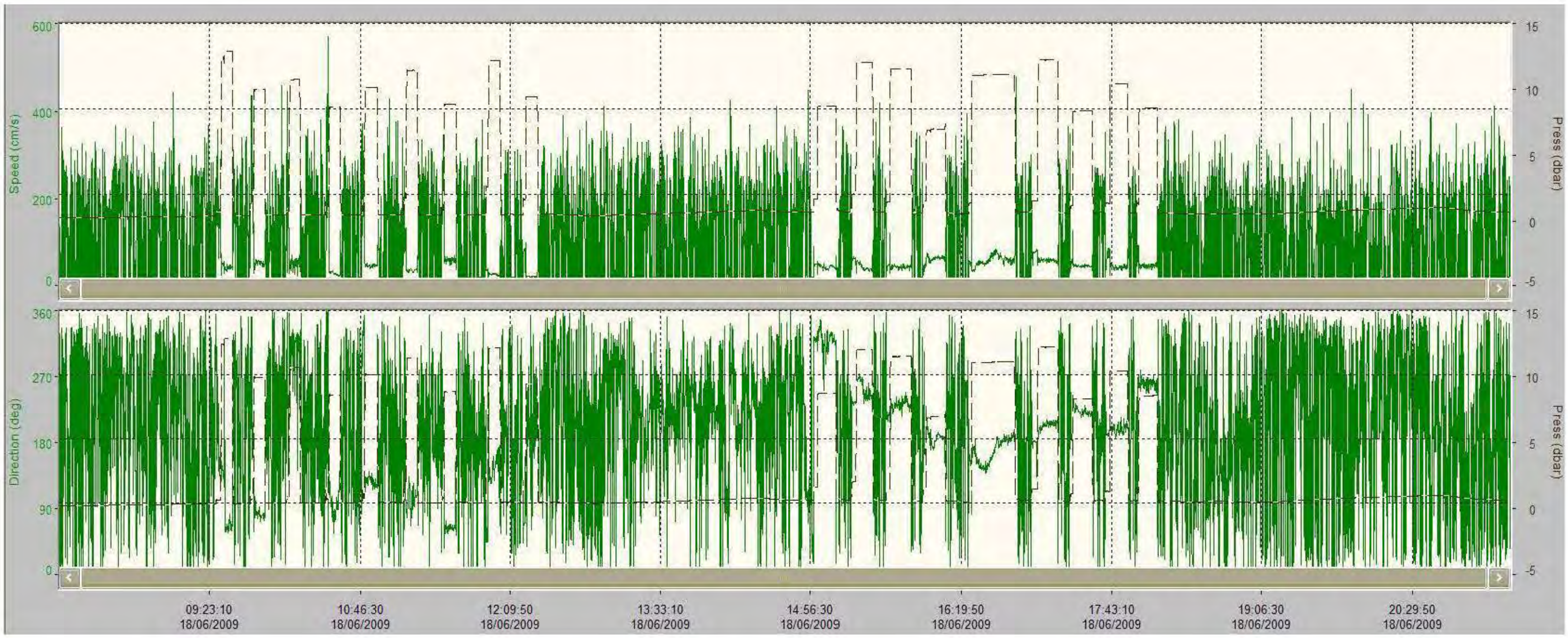


Figure 17 – Entire time series of ADV measurements taken on June 18th.

Casting Boat LISST

Nearbed suspended sediment concentration and particle grain size distribution measurements were made as part of the casting activities conducted on June 17th and 18th. These measurements were made using a LISST 100X (Laser In-Situ Scattering and Transmissometry) unit manufactured by Sequoia Scientific, Inc. The location of the anchored boat during each cast is provided in Table 2, and is noted in the header of each data file in the CD archive. An example of a processed grain size distribution is presented in Figure 18.

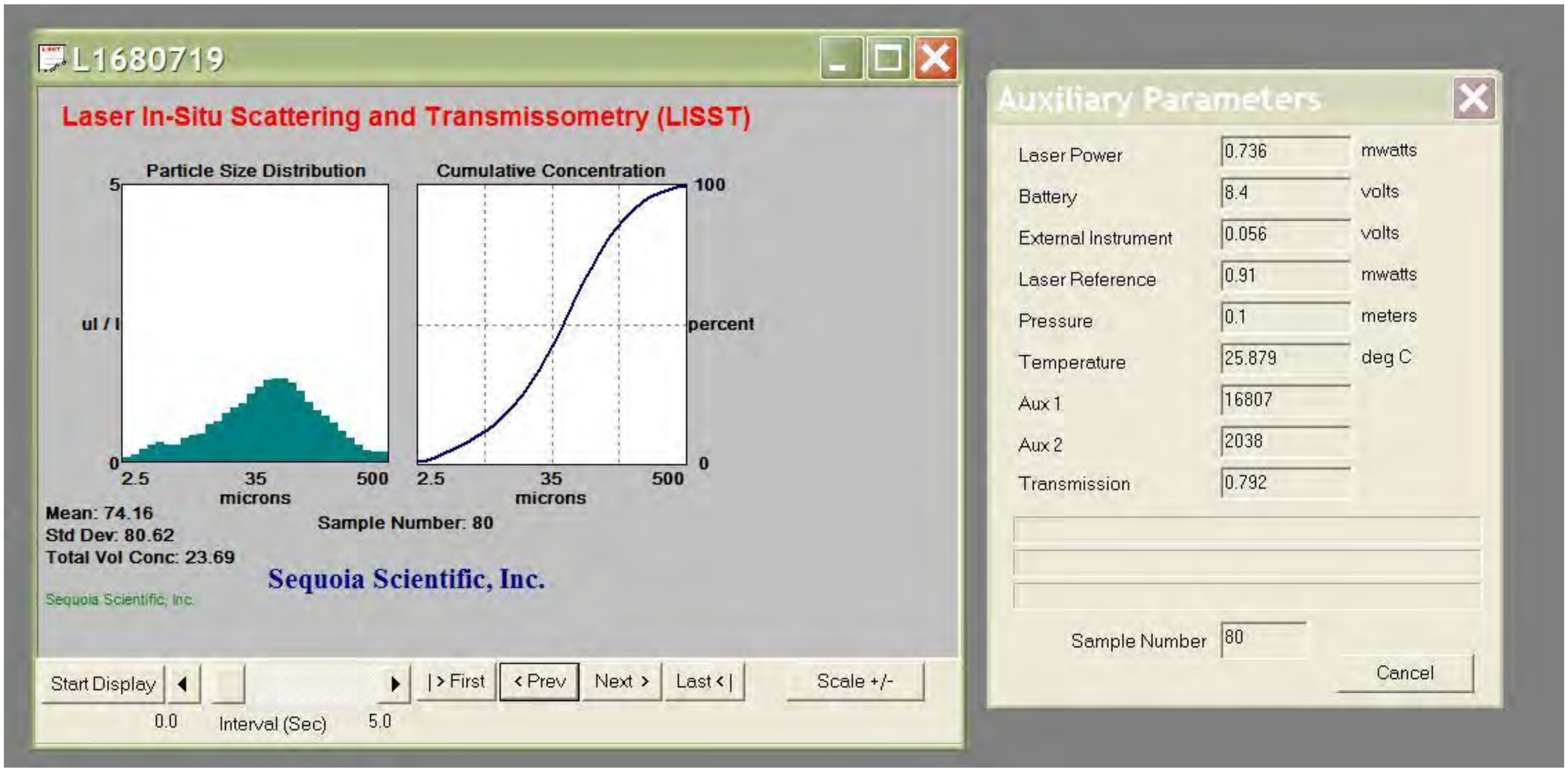


Figure 18 – Example plot of grain size distribution measured using a LISST instrument.

ADP Boat Transects

Vertical current profiles were measured along cross-channel transects at ten locations on the lower St. Johns River, during times of both peak flood and peak ebb currents. These profile transects were measured using a 1500 kHz Acoustic Doppler Profiler manufactured by Sontek, Inc. Position of the boat was continuously provided by GPS receiver. Details of each transect are provided in Table 3. A sample plot of results at CP-M#7 (near Blount Island) under ebb conditions is provided in Figure 19, and under flood conditions is provided in Figure 20.

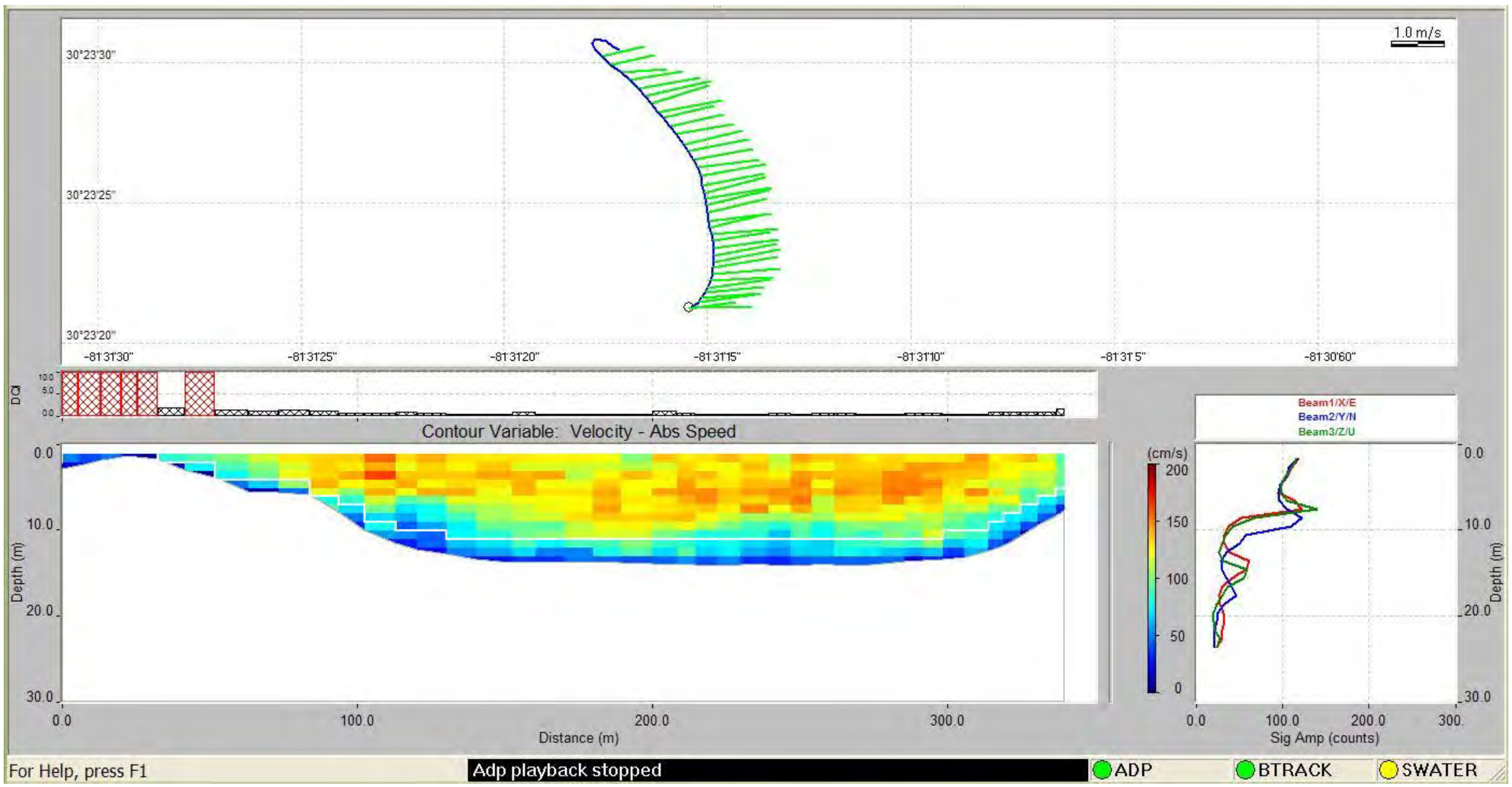


Figure 19 – Example of ADP transect measurements for CP-M#7 (Blount Island) during peak ebb currents.

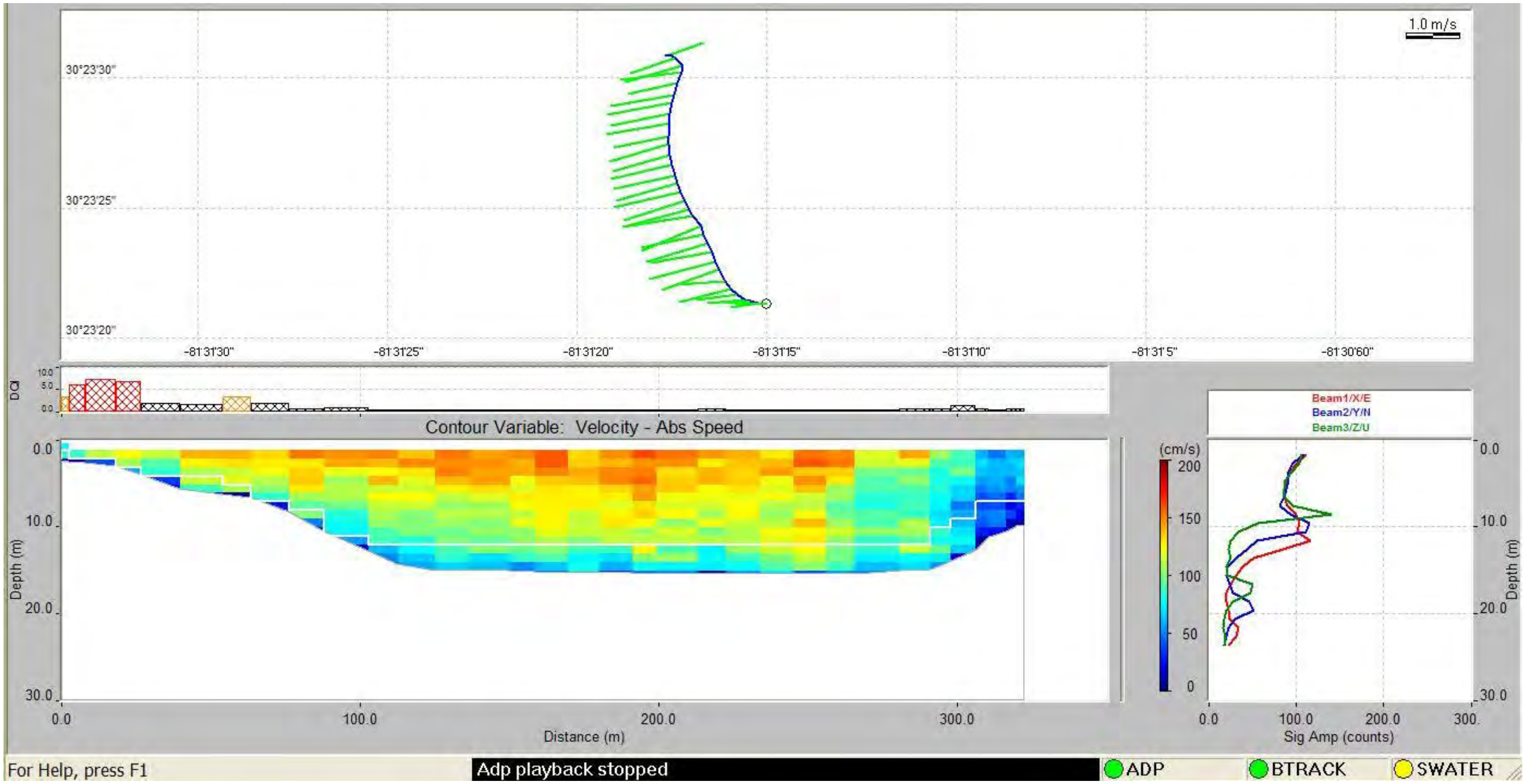


Figure 20 – Example of ADP transect measurements for CP-M#7 (Blount Island) during peak flood currents.